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REPORT NO. 629

EFFECTS OF RICOCHET ON THE MOTION OF PROJECTILES

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BALLISTIC RESEARCH LABORATORIES

ABERDEEN PROVING GROUND, MARYLAND

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TERMINAL BALLISTIC LABORATORY
PROBLEM NO. TI-148

Effects of Ricochet on the Motion of Projectiles

H. P. HITCHCOCK

10 February 1947

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ABSTRACT

The cal .50 AP Bullet M2, the 20-mm AP Shot M75, and the 20-mm Shell Mark 1 with the nose of the Practice Projectile M99, both empty and filled with lead, were fired at depressions from 5* to 10* so that they ricocheted from the ground and passed thru two velocity screens or six yaw screens. The empty Shell has a density of about 1300 gr per cu in.; the others, 2100. The AP Bullet and the empty Shell have a sectional density of about 3600 gr per sq in.; the AP Shot, 5200; and the lead-filled Shell, 6200.

*degrees

The experimental data indicate the following conclusions: The critical angle of impact is about 8* for the cal .50 Bullet and 12* for the 20-mm projectiles. The ratio of exit velocity to impact velocity depends on both the projectile and the angle of impact. The length of furrow, expressed in calibers, is largest with the AP Shot, shortest with the empty Shell; it varies from 5 to 11 projectile lengths. The ratio of the angle of ricochet to the angle of impact rapidly decreases with increase in the angle of impact; it generally decreases with increase in sectional density. Some of the projectiles have a small deflection to the left, but most of them are deflected to the right. The magnitude of the mean yaw increases considerably with increase in sectional density, but does not seem to depend on the angle of impact; its orientation occurs in all quadrants, but most of the projectiles tend to point upward and to the left. An increase in sectional density increases the maximum yaw and decreases the minimum yaw.

1. Object. Although some data regarding the velocity of a spinning projectile and the inclination of its trajectory after ricochet have been gathered, no systematic study of the motion of a projectile after ricochet has previously been made. Such a study would yield information that is needed for an accurate determination of the direction of motion and the range of a projectile after it rebounds from the earth. A knowledge of this motion is required in order to insure the safety of friendly personnel and to aim the gun properly when it is desirable to have a high explosive shell burst after ricochet (this is accomplished by means of a point detonating fuze set for a short delay).

2. Introduction. After briefly explaining the theory, we shall consider some experimental firings and study the observed velocity, length of furrow direction of trajectory, and yaw. The experiments were first conducted with a caliber 0.50 armor-piercing bullet and a 20-mm armor-piercing shot; then, in order to determine the effects of changing the density of the projectile, they were continued with a 20-mm shell, sometimes empty and sometimes filled with lead.

3. Theory.

a. According to Fowler's theory,[1] the yaw $\bar{\delta}$ of a spinning projectile may be represented as the sum of two vectors: a vector $\bar{a}_p$, which rotates about the origin at an angular velocity ω_p, and a vector $\bar{a}_n$, which rotates about the end of $\bar{a}_p$ at an angular velocity ω_n (see fig. 1). The magnitude of the yaw is denoted by δ and its orientation from the vertical plane thru the trajectory, measured clockwise in the plane normal to the trajectory, by φ. The z-axis is horizontal and directed to the right; the y-axis is perpendicular to the z-axis in the normal plane and directed upwards. Hence the projection of the yaw upon the normal plane has the following components on these axes: *

$$\delta_y = \delta \cos \varphi . \tag{1}$$

$$\delta_z = \delta \sin \varphi . \tag{2}$$

b. The stability factor s is defined by the formula:

$$s = A^2N^2/4B\,\mu , \tag{3}$$

where A and B are the axial and transverse moments of inertia respectively, N the spin, and μ a factor of the overturning moment:

$$M = \mu \sin \delta . \tag{4}$$

The moment factor may be expressed as

$$\mu = \rho\, d^3u^2K_M, \tag{5}$$

*The exact direction cosines of the axis of the projectile are cos δ, sin δ cos φ, sin δ sin φ. For small yaws, these reduce to 1, δ cos φ, δ sin φ. It is believed that the errors resulting from using this approximation for large yaws will not vitiate the general conclusions.

where ρ is the air density, d the caliber, u the velocity of the projectile relative to the air, and K_M the moment coefficient, which is a function of Mach number and yaw. Substituting (5) in (3), we obtain the expression:

$$s = A^2N^2/4B\,\rho\,d^3u^2K_M. \tag{6}$$

c. If the yaw is small, the precessional frequency is

$$\omega_p/2\pi = (1 - p)\Omega/4\pi, \tag{7}$$

if

$$p^2 = 1 - 1/s, \tag{8}$$

$$\Omega = AN/B. \tag{9}$$

Subject to the same condition, the frequency of the resultant yaw is

$$1/T = p\Omega/2\pi. \tag{10}$$

T is the period of the yaw.

These formulas should be modified to take account of large yaws and factors that affect the damping of the yaw; but they may be used as rough approximations.

d. When a spinning projectile strikes the earth, the impulse due to the impact gives its axis a large angular velocity.[2] As the projectile moves within the ground, the yaw gets very large and the trajectory curves upward. If the angle of impact is small, the projectile eventually returns to the surface and ricochets. If the earth were homogeneous, the trajectory would also curve to the right if the spin is right-handed; but actually it sometimes curves to the left. The projectile loses both linear and angular velocity; but a larger proportion of its linear velocity than its spin.

e. Let us consider a numerical example. The initial stability factor s_o should be at least 1.4 to insure small yaws under normal conditions. If the ricochet decreases the linear velocity by 50 percent and the spin by 10 percent, formula (6) shows that the stability factor s after ricochet would be 4.5, provided K_M does not change. The following table shows the corresponding values of the frequencies of precession and yaw in terms of the initial value of Ω:

	Before ricochet	After ricochet
Stability factor	1.4	4.5
p	0.534	0.882
Frequency:		
Precession	$0.116\,\Omega_o/\pi$	$0.027\,\Omega_o/\pi$
Yaw	$0.267\,\Omega_o/\pi$	$0.441\,\Omega_o/\pi$

In this case, the ratio of the frequency of precession to the frequency of yaw decreases from 0.43 to 0.06. As the stability factor approaches infinity, p approaches unity and the precessional frequency approaches zero, while the frequency of yaw approaches $\Omega/2\pi$. In the limit, then, the yawing motion may be represented by a circle with its center at the end of the fixed vector representing the precessional yaw. In practice, the precession is so slow that the yawing motion is approximately a circle for a short time.

f. The true yaw is the angle from the direction of motion of the center of gravity to the axis of the projectile. When the projectile is shot thru a paper screen normal to the trajectory, the magnitude of its yaw can be inferred from the major axis of the hole, and the orientation of the yaw is the orientation of the major axis. However, if the screen is not normal to the trajectory, the true yaw δ is different from the apparent yaw δ_a inferred from the major axis. Let us consider the projections of the trajectory and the axis of the projectile upon a vertical plane and a horizontal plane. Let the x-axis be horizontal, the y-axis vertical, and the z-axis horizontal and perpendicular to the x-axis. Let θ be the inclination of the projection of the trajectory in the vertical plane normal to the yaw screen, and ψ the deflection of the trajectory in the horizontal plane. Then the projections of the true yaw on axes normal to the trajectory may be found by means of the relations: *

$$\delta_{ay} = \delta_a \cos\varphi, \tag{11}$$

$$\delta_{az} = \delta_a \sin\varphi, \tag{12}$$

$$\delta_y = \delta_{ay} - \theta, \tag{13}$$

$$\delta_z = \delta_{az} - \psi. \tag{14}$$

Note that the y- and z-axes in the normal plane are not the same as the y- and z-axes in the vertical plane in which the apparent yaw is represented.

4. Guns. In the ricochet firings, the following guns were used:

a. A 36-inch caliber 0.50 Mann Barrel, mounted on a special firing car that could be transported across the range.

b. A 20-mm (0.787-inch) Gun M2, mounted on a converted 37-mm Carriage M4A1.

5. Ammunition.

a. The caliber 0.50 Armor-piercing Cartridge M2 contains a jacketed bullet with a hard steel core (Dwg B137655). Its physical characteristics and stability factor are:[3]

*These relations are not accurate for large values of δ, θ and ψ. See Sec 4.0 of Ref. 1 for the exact relations.

Weight	710 grains
Length	4.55 cal
Base to center of gravity	1.922 cal
Axial moment of inertia	19.71 gr. in^2
Transverse moment of inertia	217.1 gr. in^2
Pitch of rifling	15 in.
Mach No. (in stability test)	2.72
Moment coefficient	0.966
Stability factor	2.17

b. The 20-mm Armor-piercing Shot M75 (Dwg 75-2-308) is a solid steel projectile with a cavity filled with tracer composition in the rear end. The physical characteristics and stability factor of the Ball Projectile T4, which is similar to it, are:[4]

Weight	2548 grains
Length	4.11 cal
Base to center of gravity	1.806 cal
Axial moment of inertia	190.0 gr. in^2
Transverse moment of inertia	1796 gr. in^2
Pitch of rifling	25.586 cal
Muzzle Velocity (approx)	2500 fps
Moment coefficient	1.14
Stability factor	2.89

c. The 20-mm High Explosive Shell Mark 1 (Dwg 75-2-300) is a thin-walled shell which is normally filled with 175 grains of tetryl and incendiary composition and fitted with the DA Percussion Fuze No. 253, Mark I/A/(Dwg 73-1-178). In the present test, the fuze broke upon impact and was therefore replaced by the nose of the Practice Projectile M99 (Dwg 75-2-344C), which is solid except at the threaded part and is made of a zinc-base-alloy. Altho this nose also broke occasionally, it usually held together. No explosive was used; some of the shell and noses were empty, and some were filled with lead. The physical characteristics of five empty and five lead-filled Shell Mark 1 with the nose of Practice Projectile M99 were measured (see Table I); the averages are as follows:

Loading		Empty	Lead
Weight	grains	1768	3021
Length	cal	4.56	4.56
Base to center of gravity	cal	1.833	1.851
Axial moment of inertia	gr. in^2	186.1	232.1
Transverse moment of inertia	gr. in^2	1713	2209

6. Chronographs.

a. To measure the velocity of the Caliber 0.50 AP Bullet M2 after ricochet, an electronic counter chronograph was connected to a tin-foil screen and a wire-mesh screen. At a depression of 5 degrees, the point of impact was 45 feet from the muzzle, the tin-foil screen 50 feet, and the wire-mesh screen 60 feet; at a depression of 10 degrees, the point of impact was about 24 feet from the muzzle, the tin-foil screen 28 feet, and the wire-mesh screen 34 feet.

b. To measure the velocity of the 20-mm AP Shot M75 after ricochet, an electronic counter chronograph was connected to two wire-mesh screens, about 41 and 51 feet from the muzzle, for both 5 and 8 degrees depression.

c. To measure the velocity of the 20-mm Shell Mark 1 after ricochet, an electronic counter chronograph was connected to two wire-mesh screens 10 feet apart. With all projectiles, the distance between the perforations was measured after each round.

7. Yaw Screens. Six vertical screens were placed at intervals of three feet for determining the trajectory and the yaw of the projectiles. For the Caliber 0.50 Bullet and the 20-mm AP Shot, the yaw screens were made of paper; for the 20-mm Shell, they were made of cardboard. The intersections of each screen with the same vertical plane and the same horizontal plane were marked; these lines were used as coordinate axes.

8. Firings.

a. The Caliber 0.50 AP Bullet was fired in July 1944 at Michaelsville with the following results:[5]

Depression	Number of Rounds				
deg	Fired	Shed Jackets	Failed to Ricochet	Thru Velocity Screens	Thur 4 or more yaw Screens
5	12	0	2	5	
10	7	0	6	1	
5	24	2	3		16
7	17	0	3		13

b. The 20-mm AP Shot was fired in July 1944 at Michaelsville.[6] A propelling charge that gave a muzzle velocity of 2,557 fps in preliminary firings was used in the test. The results are tabulated below:

Depression	Number of Rounds			
deg	Fired	Failed to Ricochet	Thru Velocity Screens	Thru 4 or more yaw Screens
5	28	2		13
10	8	0		0
8	35	10		11
8	19	9	7	
5	7	0	7	

c. The 20-mm Shell was fired in May and June 1946 at the Light Armor Plate Range.[7] Propelling charges of 366 and 458 grains for the empty and lead-filled shells respectively were first established to give a muzzle velocity of 2,550 fps. After it was found that the shells broke upon impact on the ground, the charges were reduced and the test was finally continued with charges of 200 and 231 grains, which were established to give a muzzle velocity of 1,575 fps. The following table summarizes the results of the ricochet firings:

Depression deg.	Charge grains	Number of Rounds: Fired (E = Empty, L = Lead-filled)	Broke	Failed to Ricochet	Thru Velocity Screens	Thru 4 or more yaw Screens
5	366	3E	3	0	0	
5	235	2E	0	0	1	
5	200	9E	0	0	6	
5	458	3L	2	0	1	
5	290	2L	1	0	1	
5	285	1L	0	0	1	
5	250	5L	2	0	1	
5	231	4L	1	0	3	
8	200	18E	0	0	9	
8	250	1L	0	0	1	
8	231	9L	2	0	4	
10	200	2E	0	1	1	
10	250	2L	0	0	1	
5	200	17E	0	1		11
5	231	30L	3	4		10
8	200	16E	0	1		10
8	231	17L	7	0		10
10	200	12E	0	0		9
10	231	1L	1	0		0

9. Velocity.

a. The standard instrumental velocity of the Caliber 0.50 AP Bullet M2, fired from a 36-inch barrel, is 2,810 fps at 78 feet from the muzzle. The average instrumental velocity of some bullets taken from the lot used in this test, fired from the same Mann barrel on 19 May 1944, was 2,752 fps. This is practically a new barrel, since it had been fired only 219 rounds on 12 June and 505 rounds on 12 July. The instrumental velocity after ricochet is tabulated on Table II. At a depression of 5°, the average velocity is 1,809 fps; at a depression of 10°, the one round that ricocheted had a velocity of 329 fps.

b. The muzzle velocity of the 20-mm AP Shot M75 was about 2,557 fps. At a distance of 70 feet in air, the remaining velocity would be about 2,515 fps. The average instrumental velocity after ricochet at a depression of 5° is 2,176 fps; at a depression of 8°, 2,027 fps (see Table III).

c. The average instrumental velocities of the empty and lead-filled 20-mm Shell Mark 1 whose muzzle velocity was 1,575 fps are as follows (see Tables IV and V):

Depression deg	Loading	Velocity fps
5	Empty	1287
5	Lead	1165
8	Empty	1171
8	Lead	1191
10	Empty	1007
10	Lead	1405

d. The ratio of the velocity after ricochet to the velocity at impact is tabulated below:

Depression deg	Projectile	Velocity ratio
5	Cal .50 AP	.66
5	20-mm AP	.87
5	20-mm Empty	.82
5	20-mm Lead	.74
8	20-mm AP	.81
8	20-mm Empty	.74
8	20-mm Lead	.76
10	Cal .50 AP	.12 (1 rd)
10	20-mm Empty	.64 (1 rd)
10	20-mm Lead	.88 (1 rd)

10. Furrow

a. Most of the Caliber 0.50 AP Bullets and 20-mm AP Shot were fired into sod. Altho the gun was moved across the range occasionally, several projectiles hit the same spot. Thus each projectile after the first one at any location went thru "plowed" soil for a short distance before it encountered fresh sod. Consequently, the condition of the soil varied from round to round, but remained approximately the same from group to group. Putting every shot in a new place would have entailed moving the screens and changing the coordinate axes; this was not considered feasible.

b. The 20-mm Shell were first fired into unsodded fill which had settled for more than a year. Each furrow was filled with similar soil dug from another place and tamped with a spade. Thus the condition of the soil was fairly constant The shell that were fired into freshly tamped soil generally behaved better than those that were fired into settled soil, which had a crust (the first round was fired immediately before a heavy rain, and the test was continued two days later).

c. The length of furrow is tabulated in Tables VI to IX inclusive. Here are the averages:

Depression	Projectile	Furrow	
deg		in.	cal.
5	Cal .50 AP	16	32
5	20-mm AP	31	39
5	20-mm Empty	19	24
5	20-mm Lead	28	36
7	Cal .50 AP	14	28
8	20-mm AP	28	36
8	20-mm Empty	20	25
8	20-mm Lead	22	28
10	Cal .50 AP	35	70 (1 rd)
10	20-mm AP	37	47
10	20-mm Empty	17	22
10	20-mm Lead	19	24 (1 rd)

11. Trajectory.

a. The vertical and horizontal coordinates of the center of each hole with respect to the axes on each yaw screen were measured. By plotting these coordinates against the horizontal distance from the first screen and fitting curves to the points, the vertical and horizontal components of the trajectories were obtained (see fig. 4 to 23). The vertical components were drawn with a small curvature for the AP Bullet and Shot, but this apparent curvature was probably due to errors of measurement; they were drawn straight for the 20-mm Shell. All horizontal components were drawn as straight lines (the horizontal coordinates of the caliber 0.50 bullets on the first screen could not be used because the vertical axis was displaced an unknown distance from its proper location).

b. The slopes of the vertical and horizontal components of the trajectory - or its tangent - give the angles of inclination and deflection respectively (see Tables X to XIII inclusive). The following table gives the average value of these angles and the ratio of the inclination to the depression of the gun, which is approximately the angle of impact:

Depression	Projectile	Inclination		Deflection
deg		deg	ratio	deg
5	Cal .50 AP	14.5	2.90	Left 1.8
5	20-mm AP	11.3	2.26	Left 0.6
5	20-mm Empty	13.4	2.68	Right 5.9
5	20-mm Lead	10.1	2.02	Right 5.8
7	Cal .50 AP	10.3	1.47	Left 2.2
8	20-mm AP	12.8	1.60	Right 4.1
8	20-mm Empty	11.2	1.40	Right 5.4
8	20-mm Lead	8.1	1.01	Right 3.4
10	20-mm Empty	10.4	1.04	Right 0.5

12. Yaw.

a. The components of the true yaw of the AP Bullets and Shot were determined by the method explained in paragraph 3f and plotted (fig. 24 to 61 are small scale reproductions of these plots). Only the components of the apparent yaw of the 20-mm Shell were plotted (see fig. 62 to 105). The circle that fits the points of each round was also drawn. The center of this circle is called the mean yaw (Tables XIV to XVII). The length and orientation of the vector from the origin to the mean yaw represent the magnitude and orientation of the mean yaw. The extension of this vector cuts the circle in the points of maximum and minimum yaw (Tables XVIII to XXI).

b. The average mean, maximum and minimum yaw are tabulated below:

Depression	Projectile	Mean Yaw	Orientation	Max Yaw	Min Yaw
deg		deg	deg	deg	deg
5	Cal .50 AP	6	185	62	14
5	20-mm AP	14	231	68	8
5	20-mm Empty	5	105	58	8
5	20-mm Lead	41	332	99	5
7	Cal .50 AP	4	280	63	15
8	20-mm AP	23	283	66	10
8	20-mm Empty	17	10	66	12
8	20-mm Lead	40	320	88	7
10	20-mm Empty	18	318	58	12

c. The vectors representing the average mean yaws are shown in fig. 106. It is notable that the three vectors below the horizontal axis are for a depression of 5°; all the others are directed upwards. Furthermore, only two of the vectors point to the right of the vertical axis: these are for the empty shell at depressions of 5° and 8°. Five of the nine vectors are in the fourth (upper left-hand) quadrant. The lead-filled shell had much larger yaws than the empty ones.

13. Conclusions.

a. The effect of ricochet on the motion of four projectiles has been tested: an armor-piercing jacketed bullet, an armor-piercing shot, an empty shell, and the same shell filled with lead. The empty shell has a much lower average density than the others, but the AP bullet and the empty shell both have a low sectional density; the following table gives approximate values of these quantities.

Projectile	Average Density grains per cu in.	Sectional Density grains per sq in.
Cal .50 AP Bullet M2	2,130	3,620
20-mm AP Shot M75	1,900	5,240
20-mm Empty Shell Mark 1	1,290	3,640
20-mm Lead-filled Shell Mark 1	2,200	6,220

b. The critical angle of impact, for which less than half the shots ricochet, is between 7° and 10°, say 8°, for the cal .50 Bullet; it is more than 10°, probably about 12°, for the 20-mm projectiles. However, at 10°, many of the shots were "wild", so that it was difficult to obtain relaible data at this angle. Previous observations have indicated that the critical angle is as much as 15° to 20° with high explosive shell and, in fact, that it is approximately proportional to the square root of the ratio of the density of the soil to the density of the projectile.[8]

c. The ratio of exit velocity to impact velocity depends on both the projectile and the angle of impact. The AP Bullet has the lowest ratio; the AP Shot, the highest. This ratio is lower at 8° than at 5° angle of impact for the AP Shot and empty Shell; but is nearly constant for the lead-filled Shell (the values obtained from single rounds at 10° should not be considered, since they may be accidental). If the impact angle θ is less than the critical impact angle θ_c, the ratio of exit velocity v' to impact velocity v generally decreases in accordance with Birkhoff's law:[8]

$$v'/v = 1 - \theta/2\theta_c. \qquad (15)$$

d. The longest furrows were made by the 20-mm AP Shot. The shortest furrows, expressed in calibers, were made by the empty shell, as expected since they have the lowest density. The cal .50 Bullet made furrows about the same length, expressed in calibers, as the lead-filled Shell (the one long furrow at 10° appears to be an exception; it was probably affected by the condition of the soil). The average furrow lengths vary from 22 to 47 calibers, or from 5 to 11 projectile lengths. Their variation with angle of impact is rather irregular; other experiments have indicated that the furrow gets longer as the impact angle increases.

e. The ratio of the angle of ricochet θ' to the angle of impact θ rapidly decreases with increase in the angle of impact (see fig. 107). At 5°, this ratio is higher than the values determined by Birkhoff's law:[8]

$$\theta'/\theta = 2.5 - 1.5\,\theta/\theta_c. \qquad (16)$$

At the higher angles, the fit is fairly good on the average. Apparently, a curve would fit the points better than a straight line. No correlation between this ratio and the average density is apparent, but - excepting the 20-mm AP Shot at a depression of 8° - it decreases as the sectional density increases.

f. Some of the projectiles had a small left deflection, but most of them were deflected to the right in accordance with the theory.

g. The mean yaw increases considerably with increase in sectional density, but does not seem to depend on the angle of impact. The maximum yaw is increased only slightly by an increase in sectional density, and the minimum yaw is slightly decreased. Altho the orientation of the mean yaw occurs in all quadrants, a majority of the values are in the fourth quadrant (the projectile usually points upward and to the left).

14. Acknowledgments. Dr. G. Breit suggested the circular representation of the yaw, and derived such a motion from basic principles. Lt. A. E. Pitcher initiated the test and suggested some of the methods. Prof. G. Birkhoff and Mr. N. A. Tolch helped analyze the results. Dr. B. Garfinkle reviewed this report and pointed out the inaccuracy of the vectorial treatment of large yaws. I take this opportunity to thank these men for their assistance.

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LIST OF TABLES

TABLE I

Physical Characteristics

20-mm Shell Mark 1 with Nose 75-2-344C

Loading	Shell No.	Weight grains	Length in.	Bour. Diam in.	Body Diam in.	C.G. to Base Cal.	Moments of Inertia - gr.in^2 Axial	Transverse
Empty	1	1763	3.571	.7845	.7795	1.824	186.1	1696
	2	1764	3.582	.7840	.7795	1.828	186.4	1711
	3	1767	3.588	.7833	.7783	1.834	185.5	1713
	4	1773	3.585	.7842	.7790	1.829	186.4	1722
	5	1772	3.589	.7837	.7789	1.849	186.3	1723
	Mean	1768	3.583	.7839	.7790	1.833	186.1	1713
	P. E. of Mean	1.4	.0022	.0028	.00015	.0029	.11	4.2
Lead	1	2972	3.578	.7830	.7775	1.839	228.9	2169
	2	3012	3.568	.7842	.7781	1.849	230.9	2216
	3	3026	3.598	.7839	.7782	1.855	232.1	2222
	4	3030	3.572	.7831	.7785	1.852	232.3	2209
	5	3065	3.589	.7847	.7794	1.858	236.3	2232
	Mean	3021	3.581	.7838	.7783	1.851	232.1	2209
	P.E. of Mean	10.1	.0037	.0002	.0002	.0022	.80	23.6

TABLE II

Velocity of Caliber 0.50 A.P. Bullet M2
After Ricochet

Cal .50 Mann Barrel No. 45-1 (36")
Fired 4 July 1944 at Michaelsville

Depression	5°	10°
Gun to 1st screen	50 ft	28 ft
1st to 2d screen	10 ft	6 ft

Note: The slant distance between the perforations of each bullet was measured and used in calculating the velocity.

Depression deg	Round No.	Velocity fps
5	2	2006
	4	1605
	7	1959
	8	1715
	12	1758
	Avg.	1809
10	15	329

TABLE III

Velocity of 20-mm AP Shot M75 after ricochet

20-mm Automatic Gun M2 at Michaelsville

Date, 1944, July	27	28
Gun Depression	8°	5°
Gun to 1st screen	41'	41'8"

Depression deg.	Round No.	Slant distance between perfora-tions in.	Velocity fps
8	75	128.55	2021
	76	126.55	1998
	82	126.94	2062
	Avg	------	2027
5	92	105.44	2254
	93	108.31	2006
	95	106.81	2236
	96	106.25	2164
	97	104.20	2220
	Avg	------	2176

TABLE IV

Velocity of 20-mm Empty Shell Mark 1 with Nose 75-2-344C after Ricochet

20-mm Gun M2 fired at Light Armor Plate Range On 23 May and 6 June 1946

Gun to 1st screen, approximately 18 ft
1st to 2d screen, 10 ft

Note: The slant distance between the perforations of each bullet was measured and used in calculating the velocity.

Depression deg	Muzzle Velocity (est) fps	Round No.	Weight (Proj) grains	Velocity (Inst.) fps
5	1780	3576	1765	1603
	1575	3580	1768	1298
	1575	3582	1768	1263
	1575	3586	1771	1389
	1575	3609	1774	1241
	1575	3611	1774	1275
	1575	3613	1768	1255
	1575	Avg	1770	1287
8	1575	3592	1761	898
	1575	3615	1776	1545
	1575	3623	1776	938
	1575	3625	1768	1450
	1575	3635	1767	1193
	1575	3636	1765	1120
	1575	3637	1762	1089
	1575	3638	1766	1150
	1575	3640	1765	1157
	1575	Avg	1767	1171
10	1575	3594	1767	1007

TABLE V

Velocity of 20-mm Lead-filled Shell Mark 1 with Nose 75-2-344C after Ricochet

20-mm Gun M2 fired at Light Armor Plate Range

On 23 May and 6 June 1946

Gun to 1st screen, approximately 18 ft
1st to 2d screen, 10 ft

Note: The slant distance between the perforations of each bullet was measured and used in calculating the velocity.

Depression deg	Muzzle Velocity (est) fps	Round No.	Weight (Proj) grains	Velocity (Inst.) fps
5	2550	3573	3100	1841
	1880	3575	3037	1669
	1880	3575	3049	1329
	1700	3585	2973	1361
	1575	3608	2991	1242
	1575	3610	3011	1014
	1575	3612	3070	1238
	1575	Avg	3024	1165
8	1700	3591	3025	1429
	1575	3622	2948	1031
	1575	3624	3058	1369
	1575	3626	3025	1216
	1575	3631	3032	1147
	1575	Avg	3016	1191
10	1700	3593	3022	1405

TABLE VI

Length of Furrow of
Cal .50 AP Bullet M2

Depression - deg.								
5			7			10		
Date 1944 July	Round No.	Furrow in.	Date 1944 July	Round No.	Furrow in.	Date 1944 July	Round No.	Furrow in.
4	1	14	7	12	12	4	15	35
	2	17		13	18			
	4	16		14	12			
	5	12		15	11			
	6	14		16	9			
	7	19		17	14			
	8	20		18	13			
	9	14		19	13			
	10	16		20	12			
	11	23		21	10			
	12	22		22	14			
				25	13			
5	2	35		26	14			
	4	25		27	28			
	6	18						
	7	20						
	8	10						
	10	14						
	11	20						
	12	10						
	13	18						
	14	16						
7	1	12						
	2	14						
	3	12						
	4	10						
	5	11						
	6	12						
	7	12						
	8	9						
	9	10						
	10	17						
	Avg	15.87		Avg	13.79			35

TABLE VII

Length of Furrow of 20-mm AP Shot M75

Depression - deg								
5			8			10		
Date 1944 July	Round No.	Furrow in.	Date 1944 July	Round No.	Furrow in.	Date 1944 July	Round No.	Furrow in.
25	2	20	26	37	18	26	30	40
	3	20		38	24		31	36
	4	24		39	21		32	47
	5	46		41	24		34	24
	6	47		42	30		35	36
	7	31		43	20			
	8	46		44	22			
	9	24						
	10	20	27	54	17			
	11	24		57	39			
	12	24		59	60			
	13	30						
	15	24						
	16	18						
	17	24						
	19	26						
	20	36						
26	21	34						
	22	36						
	23	36						
	24	48						
	26	45						
	Avg	31		Avg	27.5		Avg	37

TABLE VIII

Length of Furrow of 20-mm Empty Shell Mark 1
with Nose 75-2-344C

Depression deg	Muzzle Velocity (est) fps	Round No.	Weight (Proj) grains	Furrow in.
5	2550	3570	1763	23
	2550	3572	1765	10
	2550	3574	1763	24
	1780	3576	1765	11
	1780	3578	1754	24
	1575	3580	1768	18
	1575	3582	1768	12
	1575	3584	1763	18
	1575	3586	1771	15
	1575	3588	1767	24
	1575	3590	1763	20
	1575	3609	1774	15
	1575	3611	1774	22
	1575	3613	1766	19
	1575	3641	1772	21
	1575	3642	1767	15
	1575	3643	1764	21
	1575	3644	1765	23
	1575	3645	1773	20
	1575	3646	1767	18
	1575	3647	1765	20
	1575	3648	1765	24
	1575	3649	1775	18
	1575	3650	1758	20
	1575	3651	1768	22
	1575	3652	1767	24
	1575	3653	1768	18
	1575	3682	1764	16
	1575	3683	1771	26
	1575	3684	1766	23
	1575	3685	1763	13
	1575	Avg	1767	19.4
10	1575	3594	1767	15
	1575	3596	1767	20
	1575	3722	1774	14
	1575	3723	1767	15
	1575	3724	1766	18
	1575	3725	1780	18
	1575	3726	1776	18
	1575	3727	1771	18
	1575	3728	1767	15

Depression deg	Muzzle Velocity (est) fps	Round No.	Weight (Proj) grains	Furrow in.
8	1575	3592	1761	15
	1575	3615	1776	10
	1575	3617	1774	22
	1575	3619	1766	21
	1575	3621	1776	23
	1575	3623	1776	21
	1575	3625	1768	21
	1575	3627	1764	21
	1575	3629	1772	21
	1575	3632	1765	15
	1575	3633	1769	17
	1575	3634	1769	18
	1575	3635	1767	21
	1575	3636	1765	20
	1575	3637	1762	19
	1575	3638	1766	22
	1575	3639	1765	21
	1575	3640	1765	21
	1575	3688	1769	18
	1575	3689	1774	21
	1575	3690	1759	28
	1575	3691	1770	27
	1575	3692	1761	27
	1575	3693	1774	33
	1575	3694	1767	27
	1575	3695	1755	16
	1575	3696	1767	17
	1575	3703	1767	15
	1575	3704	1772	15
	1575	3705	1768	17
	1575	3706	1764	17
	1575	3707	1766	16
	1575	3708	1768	24
	1575	3709	1769	20
	1575	Avg	1768	20.2
10	1575	3729	1769	18
	1575	3730	1764	16
	1575	3731	1762	22
	1575	3732	1763	17
	1575	3733	1772	16
	1575	Avg	1769	17.1

TABLE IX

Length of Furrow of 20-mm Lead-filled Shell Mark 1

with Nose 75-2-344C

Depression deg	Muzzle Velocity (est) fps	Round No.	Weight (Proj) grains	Furrow in.
5	2550	3569	3065	19
	2550	3571	3000	16
	2550	3573	3100	15
	1860	3575	3037	21
	1700	3577	3094	24
	1880	3579	3049	23
	1880	3581	3066	22
	1700	3583	3065	20
	1700	3585	2973	19
	1700	3587	3003	18
	1700	3589	3000	19
	1575	3608	2991	13
	1575	3610	3011	15
	1575	3612	3070	16
	1575	3614	3025	23
	1575	3654	2971	24
	1575	3655	2999	20
	1575	3656	2988	24
	1575	3657	3017	26
	1575	3658	3059	32
	1575	3659	2979	28
	1575	3660	3023	22
	1575	3661	3050	29
	1575	3662	2998	18
	1575	3663	3000	28
	1575	3664	2990	36
	1575	3665	3980	42
	1575	3666	3027	24
	1575	3667	2985	28
	1575	3668	3033	35
	1575	3669	2996	50
	1575	3670	3068	24
	1575	3671	3030	44
	1575	3672	3010	36
	1575	3673	2989	18
	1575	3674	3017	26
	1575	3675	3080	29
	1575	3676	2991	30
	1575	3677	3062	24
	1575	3678	3043	24
	1575	3679	3008	35
	1575	3680	3066	30
	1575	3681	3045	46
	1575	3686	3025	22
	1575	3687	3013	21
	1575	Avg	3019	27.7
8	1700	3591	3025	21
	1575	3616	2974	21
	1575	3618	3054	22
	1575	3620	2950	23
	1575	3622	2948	22
	1575	3624	3058	16
	1575	3626	3025	25
	1575	3628	3037	28
	1575	3630	3032	23
	1575	3631	3032	28
	1575	3697	3034	24
	1575	3698	3008	18
	1575	3699	3051	21
	1575	3700	3056	23
	1575	3701	3011	20
	1575	3702	3010	16
	1575	3710	3047	22
	1575	3711	3004	22
	1575	3712	3026	23
	1575	3713	3073	23
	1575	3714	3037	25
	1575	3715	3039	26
	1575	3716	3061	25
	1575	3717	3015	15
	1575	3718	3029	26
	1575	3719	3026	20
	1575	3720	3028	25
	1575	Avg	3026	22.4
10	1700	3593	3022	15
	1700	3595	3044	17
	1575	3721	3030	19

TABLE X

Direction of Trajectory of
Cal .50 AP Bullet M2 at first screen

Depression deg	Date 1944 July	Round No.	Inclination deg	Deflection deg*
5	5	6	13.6	-4.9
		7	13.4	-6.9
		10	21.2	-3.5
		11	14.0	-5.2
		13	12.4	5.4
	7	1	20.0	-9.6
		2	17.7	5.9
		3	19.3	-2.1
		4	4.8	1.4
		5	12.8	-1.7
		6	20.3	-1.8
		7	13.5	-2.8
		10	5.6	2.0
7	7	12	2.6	2.8
		14	4.1	-4.1
		15	6.0	-3.1
		18	20.2	-8.3
		20	8.7	-2.8
		21	21.7	-3.8
		27	8.8	3.7
5	Mean		14.5	-1.8
	PE of mean		.97	.85
7	Mean		10.3	-2.2
	PE of mean		1.94	1.06

*Positive to the right.

TABLE XI

Direction of Trajectory of
20-mm AP Shot M75 at first screen

Depression deg	Round No.	Inclination deg	Deflection deg*
5	3	14.2	-0.2
	12	10.3	2.6
	13	8.0	-1.0
	16	12.4	-4.3
	20	18.4	6.0
	22	6.9	-4.8
	23	11.8	-1.4
	24	8.2	-1.5
8	37	15.6	2.1
	38	9.8	3.6
	39	13.5	-1.5
	54	7.6	1.6
	61	13.0	5.7
	62	12.1	4.9
	63	12.8	7.8
	64	16.3	7.3
	71	14.1	5.0
5	Mean	11.3	-.58
	PE of mean	.95	.84
8	Mean	12.8	+4.1
	PE of mean	.64	.66

*Positive to the right.

TABLE XII

Direction of Trajectory of 20-mm
Empty Shell Mark 1 with Nose 75-2-344C

Depression deg	Round No.	Inclination deg	Deflection deg*
5	3641	16.8	8.9
	3642	16.8	6.2
	3643	17.2	7.9
	3645	10.5	8.7
	3646	14.3	9.9
	3647	14.0	1.7
	3649	13.8	3.1
	3652	10.0	0.7
	3682	7.4	5.6
	3685	13.0	6.7
8	3689	8.0	7.0
	3691	19.6	9.4
	3695	19.5	12.4
	3695	11.0	4.0
	3696	10.3	3.0
	3703	7.8	5.7
	3704	5.7	0.5
	3705	10.1	1.4
	3706	6.7	1.4
	3709	13.0	9.4
10	3722	5.2	-2.6
	3723	13.9	8.3
	3724	12.4	0.3
	3725	9.5	3.0
	3726	13.0	-2.4
	3730	5.3	.6
	3731	16.0	-3.0
	3732	8.7	0.2
	3733	9.7	0.1
5	Mean	13.4	5.9
	PE of Mean	.69	.68
8	Mean	11.2	5.4
	PE of Mean	1.05	.86
10	Mean	10.4	.50
	PE of Mean	.84	.79

*Positive to the right.

TABLE XIII

Direction of Trajectory of 20-mm
Lead-filled Shell Mark 1 with Nose 75-2-344C

Depression deg	Round No.	Inclination deg	Deflection deg*
5	3654	14.9	7.1
	3659	14.7	8.6
	3660	9.0	4.6
	3673	6.1	3.6
	3674	6.1	2.2
	3678	8.9	7.5
	3687	10.9	7.1
8	3697	9.8	4.6
	3699	9.8	.8
	3701	7.3	2.1
	3702	6.7	5.7
	3712	5.5	1.7
	3714	10.7	9.8
	3719	7.2	1.9
	3720	7.5	1.0
5	Mean	10.1	5.8
	PE of mean	.93	.60
8	Mean	8.1	+3.4
	PE of mean	.43	.74

*Positive to the right.

TABLE XIV

Mean Yaw of Cal .50 AP Bullet M2
After Ricochet

Depression deg	Date 1944 July	Round No.	Yaw - deg Vertical	Horizontal	Magnitude	Orientation
5	5	6	6.2	12.7	13.1	64
		7	2.8	-36.7	36.8	274
		10	-22.3	42.4	47.9	118
		11	- 8.5	12.8	15.4	123
		13	18.0	15.4	23.7	41
	7	1	- 6.4	-15.5	16.8	247
		2	8.1	-22.2	23.8	290
		3	7.9	-26.1	27.3	287
		4	-43.1	- 4.8	43.2	186
		5	- 8.2	16.2	18.2	117
		6	-16.2	- 8.2	17.4	208
		7	-10.0	-17.8	20.2	240
		10	- 4.9	25.4	25.9	101
7		12	-21.8	- 1.6	21.9	184
		14	22.8	2.8	23.0	7
		15	- 8.9	36.0	37.0	104
		18	28.0	-41.0	49.7	304
		20	- 9.0	-18.1	20.2	243
		21	3.9	- 5.0	6.4	308
		26	2.0	-24.7	24.7	279
		27	-11.5	19.5	22.5	121
5			- 5.89* 2.94**	- 0.49* 4.33**	6.3***	185***
7			0.69* 4.12**	- 4.01* 5.84**	4.1***	280***

*Mean **Probable error of mean ***Calculated from the mean vertical and horizontal yaws.

TABLE XV

Mean Yaw of 20-mm AP Shot M75 after Ricochet

Depression deg	Date 1944 July	Round No.	Yaw - deg			
			Vertical	Horizontal	Magnitude	Orientation
5	25	3	- 3.2	-57.8	57.8	267
		12	13.0	-35.5	37.9	290
		13	2.2	-23.9	24.0	275
		16	- 8.8	-21.7	23.4	248
		20	-25.5	32.1	41.0	129
	26	22	-28.3	- 1.0	28.3	182
		23	- 9.0	7.2	13.1	141
		24	- 9.1	16.0	18.5	120
8	26	37	11.1	-17.0	20.2	303
		38	-22.5	-20.0	30.0	222
		39	10.5	- 8.9	13.8	320
		54	8.5	-35.8	36.8	283
		61	- 8.6	-33.9	34.8	256
		62	12.8	-35.5	37.6	290
		63	10.8	-18.1	21.0	300
		64	21.0	-44.2	49.0	295
	27	71	2.3	9.1	9.7	75
5			-8.59*	-10.59*	13.6***	231***
			3.23**	7.03**		
8			+5.10*	-22.70*	23.3***	283***
			2.95**	3.72**		

*Mean **Probable error of mean ***Calculated from the mean vertical and horizontal yaws.

TABLE XVI

Mean Yaw of 20-mm Empty Shell Mark 1 with Nose 75-2-344C

Depression deg	Round No.	Yaw - deg			
		Vertical	Horizontal	Magnitude	Orienta-tion
5	3641	-14.6	-0.4	14.6	181
	3642	- 6.2	20.0	21.0	107
	3643	-10.0	19.0	21.7	118
	3645	-21.7	2.6	21.8	173
	3646	-18.0	28.8	34.0	122
	3647	25.4	5.2	26.4	11
	3649	.4	9.7	9.7	87
	3652	13.4	-35.7	38.2	110
	3682	24.8	-27.4	37.2	312
	3685	- 5.7	24.0	24.7	103
8	3689	23.8	-19.0	30.5	322
	3691	39.2	-12.7	41.1	341
	3694	-14.0	27.2	30.6	107
	3695	4.7	20.6	21.1	77
	3696	18.0	13.7	22.6	38
	3703	4.0	23.0	23.4	81
	3704	16.7	-14.0	21.8	321
	3705	18.6	-25.0	31.0	307
	3706	33.5	2.4	33.6	4
	3709	21.0	12.2	24.3	30
10	3722	9.7	-31.4	32.9	287
	3723	16.2	10.0	19.0	32
	3724	17.4	-20.0	26.4	312
	3725	23.5	-24.5	34.0	314
	3726	9.1	- 8.4	12.3	317
	3730	21.3	-21.6	30.2	314
	3731	- 6.3	10.6	12.3	121
	3732	16.1	-19.0	24.8	310
	3733	14.4	- 5.1	15.3	341
5		- 1.22* 3.63**	4.58* 1.44**	4.7***	105***
8		16.55* 3.27**	2.84* 4.08**	16.8***	10***
10		13.49* 1.97**	-12.16* 3.37**	18.2***	318***

*Mean **Probable error of mean ***Calculated from the mean vertical and horizontal yaws.

TABLE XVII

Mean Yaw of 20-mm Lead-filled Shell Mark 1 with Nose 75-2-344C

Depression deg	Round No.	Yaw - deg			
		Vertical	Horizontal	Magnitude	Orientation
5	3654	48.2	13.7	50.1	16
	3659	36.6	-28.9	46.6	322
	3660	32.9	-22.9	40.0	325
	3673	38.3	13.4	40.6	20
	3674	17.5	-54.3	57.0	288
	3678	37.8	-34.2	50.9	318
	3687	42.5	-21.4	48.3	334
8	3697	27.4	-48.0	55.3	300
	3699	25.0	-21.1	32.7	320
	3701	27.6	-28.4	39.6	314
	3702	35.8	-13.8	38.3	339
	3712	18.2	-27.9	33.3	303
	3714	42.7	-22.7	48.3	332
	3719	46.3	-21.3	50.9	335
	3720	24.1	-25.9	35.4	313
5		36.26* 2.44**	-19.23* 6.34**	41.04***	332***
8		30.89* 2.32**	-26.14* 2.38**	40.47***	320***

*Mean **Probable error of mean. ***Calculated from the mean vertical and horizontal yaws.

TABLE XVIII

Maximum and Minimum Yaws of
Cal .50 AP Bullet M2 after Ricochet

Depression deg	Date 1944 July	Round No.	Maximum Yaw deg	Minimum Yaw deg
5	5	6	37	8
		7	87	13
		10	81	7
		11	47	17
		13	58	11
	7	1	58	25
		2	48	0
		3	65	11
		4	84	1
		5	56	20
		6	77	42
		7	61	20
		10	49	2
7	7	12	70	26
		14	53	8
		15	88	14
		18	88	10
		20	60	20
		21	37	25
		27	48	2
5	Mean		62	14
	PE of mean		3.0	2.2
7	Mean		63	15
	PE of mean		5.0	2.3

TABLE XIX

Maximum and Minimum Yaw of
20-mm AP Shot M75 after Ricochet

Depression deg	Round No.	Maximum Yaw deg	Minimum Yaw deg
5	3	119	3
	12	80	4
	13	57	9
	16	61	14
	20	82	0
	22	70	14
	23	31	9
	24	46	10
8	37	53	13
	38	91	31
	39	47	20
	54	76	2
	61	74	4
	62	78	3
	63	48	6
	64	96	2
	71	31	12
5	Mean	68	7.9
	PE of mean	6.4	1.5
8	Mean	66	10.3
	PE of mean	5.0	2.2

TABLE XX

Maximum and Minimum Yaw of 20-mm
Empty Shell Mark 1 with Nose 75-2-344C

Depression deg	Round No.	Maximum Yaw deg	Minimum Yaw deg
5	3641	51	22
	3642	52	10
	3643	46	2
	3645	56	13
	3646	74	6
	3647	60	8
	3649	31	12
	3652	82	3
	3682	80	6
	3685	52	3
8	3689	88	28
	3691	84	2
	3694	49	12
	3695	48	6
	3696	59	14
	3703	57	10
	3704	64	20
	3705	73	12
	3706	85	17
	3709	51	3
10	3722	74	8
	3723	46	8
	3724	69	16
	3725	75	7
	3726	42	18
	3730	74	13
	3731	32	7
	3732	67	17
	3733	46	15
5	Mean	58	8.5
	PE of mean	3.4	1.3
8	Mean	66	12.4
	PE of mean	3.3	1.7
10	Mean	58	12.1
	PE of mean	3.7	1.2

TABLE XXI

Maximum and Minimum Yaw of 20-mm
Lead-filled Shell Mark 1 with Nose 75-2-344C

Depression deg	Round No.	Maximum Yaw deg	Minimum Yaw deg
5	3654	102	2
	3659	95	1
	3660	90	10
	3673	94	13
	3674	111	3
	3678	105	3
	3687	95	1
8	3697	112	1
	3699	74	9
	3701	88	9
	3702	87	10
	3712	76	10
	3714	91	5
	3719	95	7
	3720	79	8
5	Mean	99	4.7
	PE of mean	1.9	1.2
8	Mean	87.8	7.4
	PE of mean	0.9	0.7

FIGURES 1 to 105 inclusive

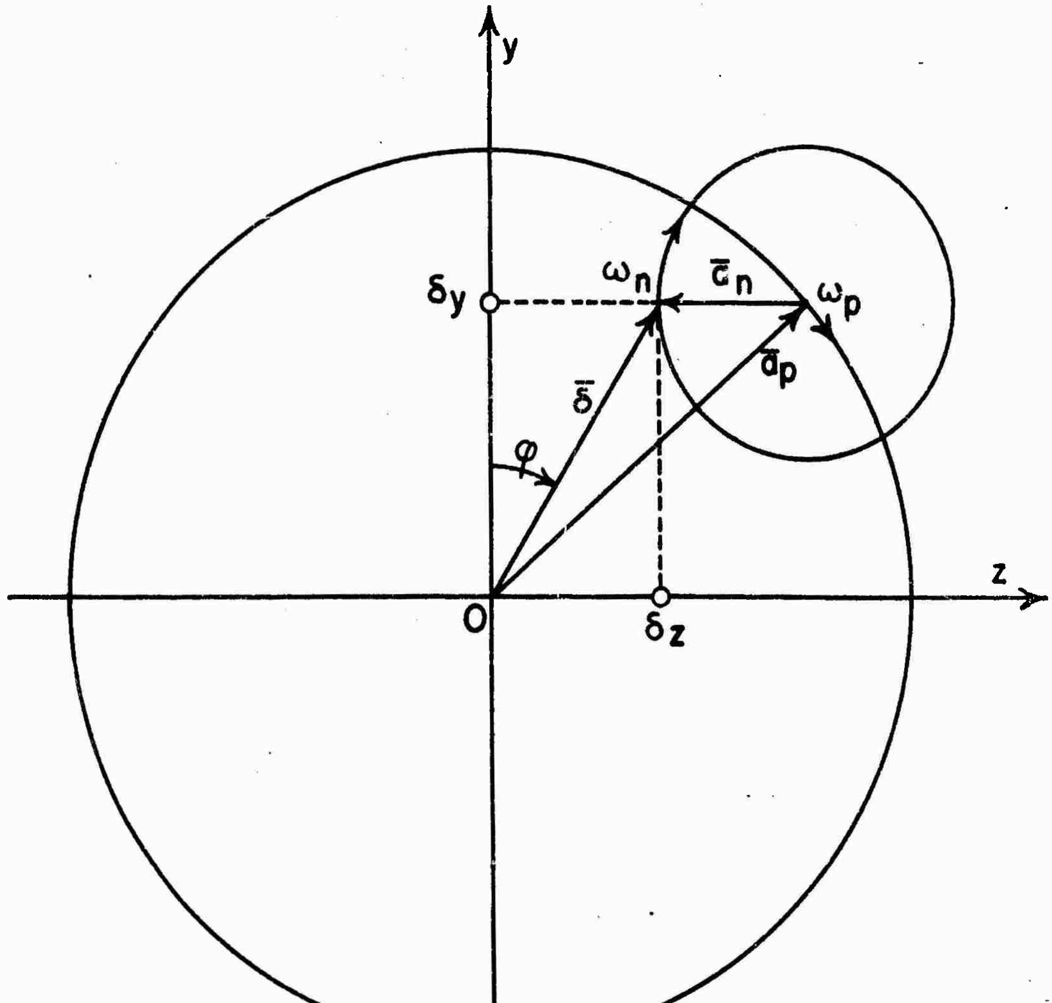
appear on

Pages 35 to 137 inclusive

LIST OF FIGURES

NOTE: These reproductions are smaller than the original drawings. The scales indicated on Figures 2 to 21 pertain to the original coordinates with 20 lines per inch.

FIGURE I
COMPOSITION OF YAW VECTOR



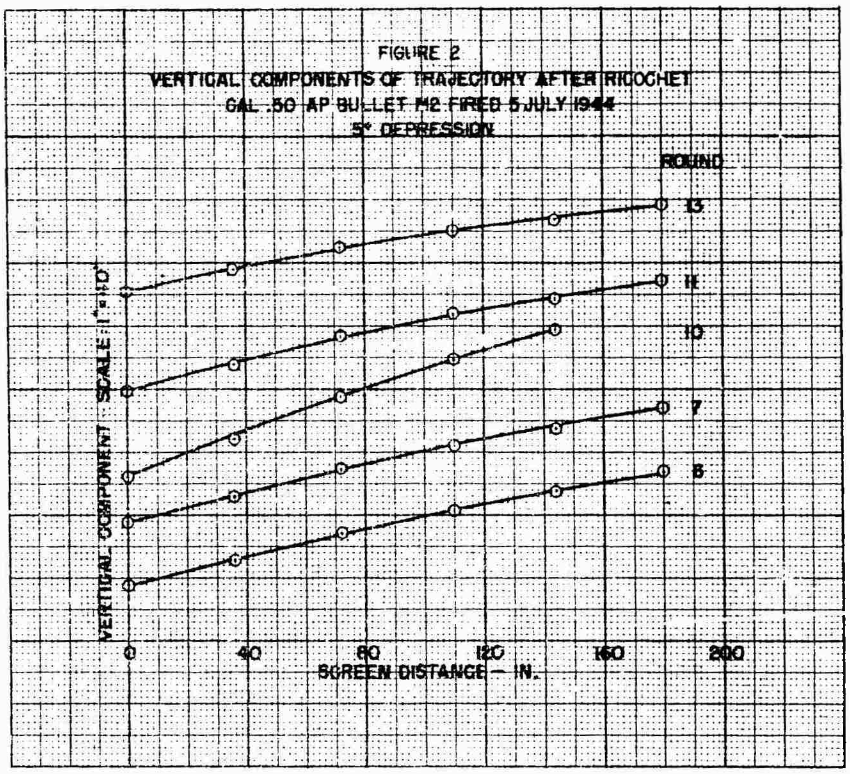


FIGURE 2
VERTICAL COMPONENTS OF TRAJECTORY AFTER RICOCHET
CAL .50 AP BULLET M2 FIRED 5 JULY 1944
5° DEPRESSION

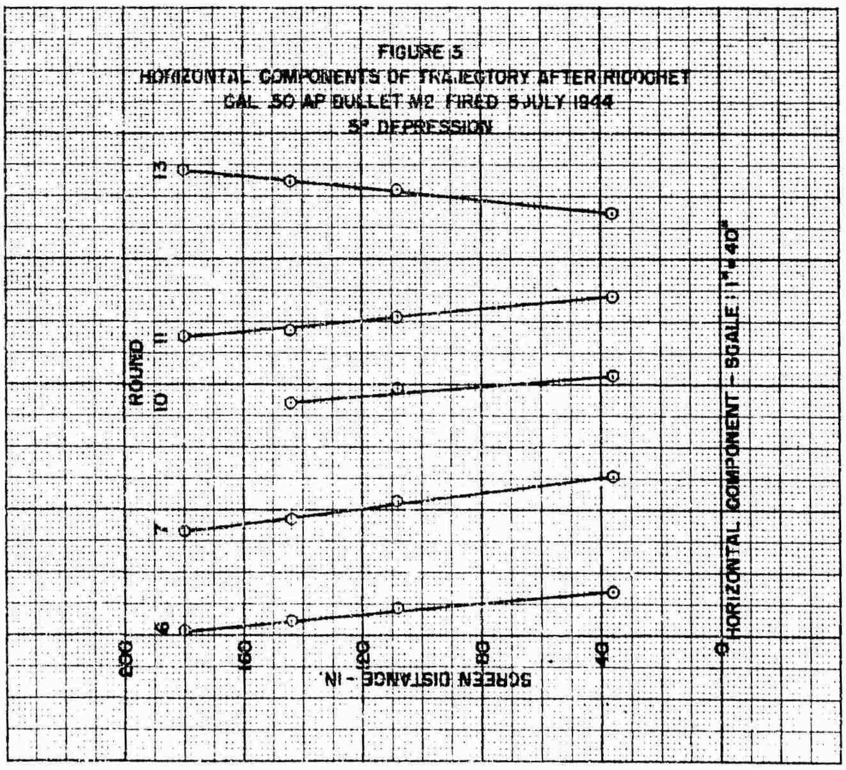


FIGURE 3
HORIZONTAL COMPONENTS OF TRAJECTORY AFTER RICOCHET
CAL .50 AP BULLET M2 FIRED 5 JULY 1944
5° DEPRESSION

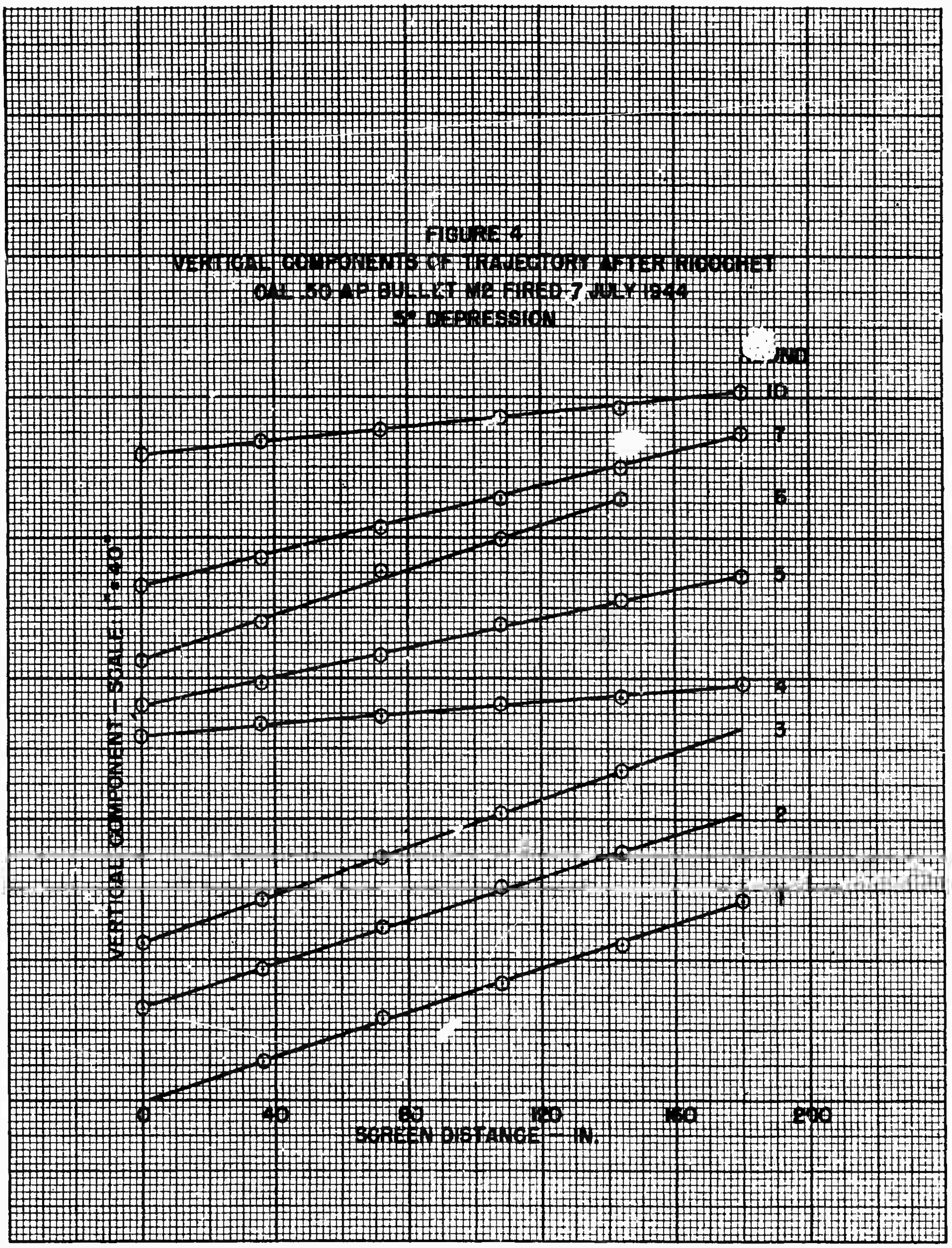


FIGURE 4
VERTICAL COMPONENTS OF TRAJECTORY AFTER RICOCHET
CAL .50 AP BULLET M2 FIRED 7 JULY 1944
5° DEPRESSION
10
7
6
5
4
3
2
1
VERTICAL COMPONENT – SCALE 1"=40"
0
40
80
120
160
200
SCREEN DISTANCE – IN.

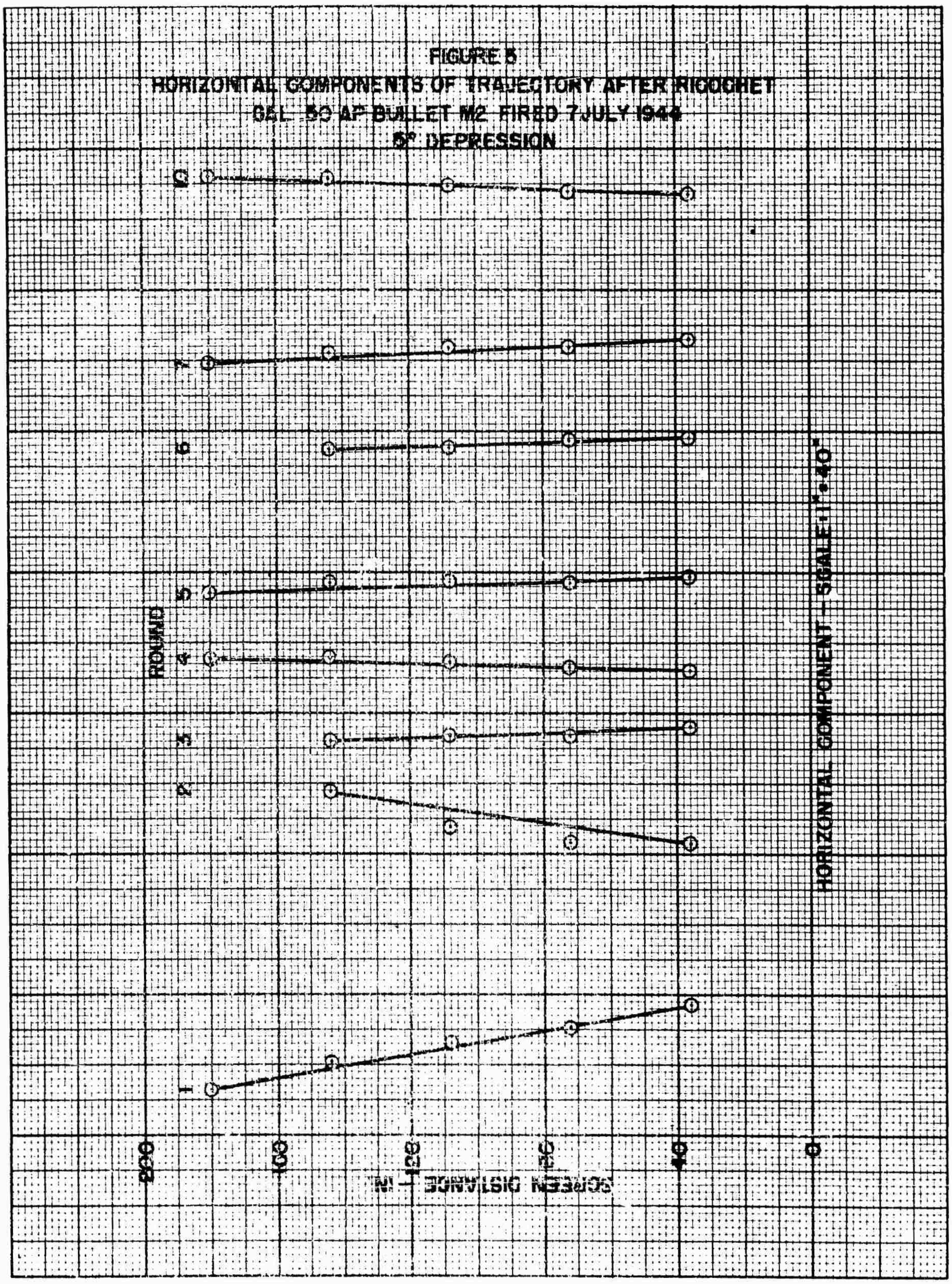


FIGURE 5
HORIZONTAL COMPONENTS OF TRAJECTORY AFTER RICOCHET
CAL .50 AP BULLET M2 FIRED 7 JULY 1944
5° DEPRESSION

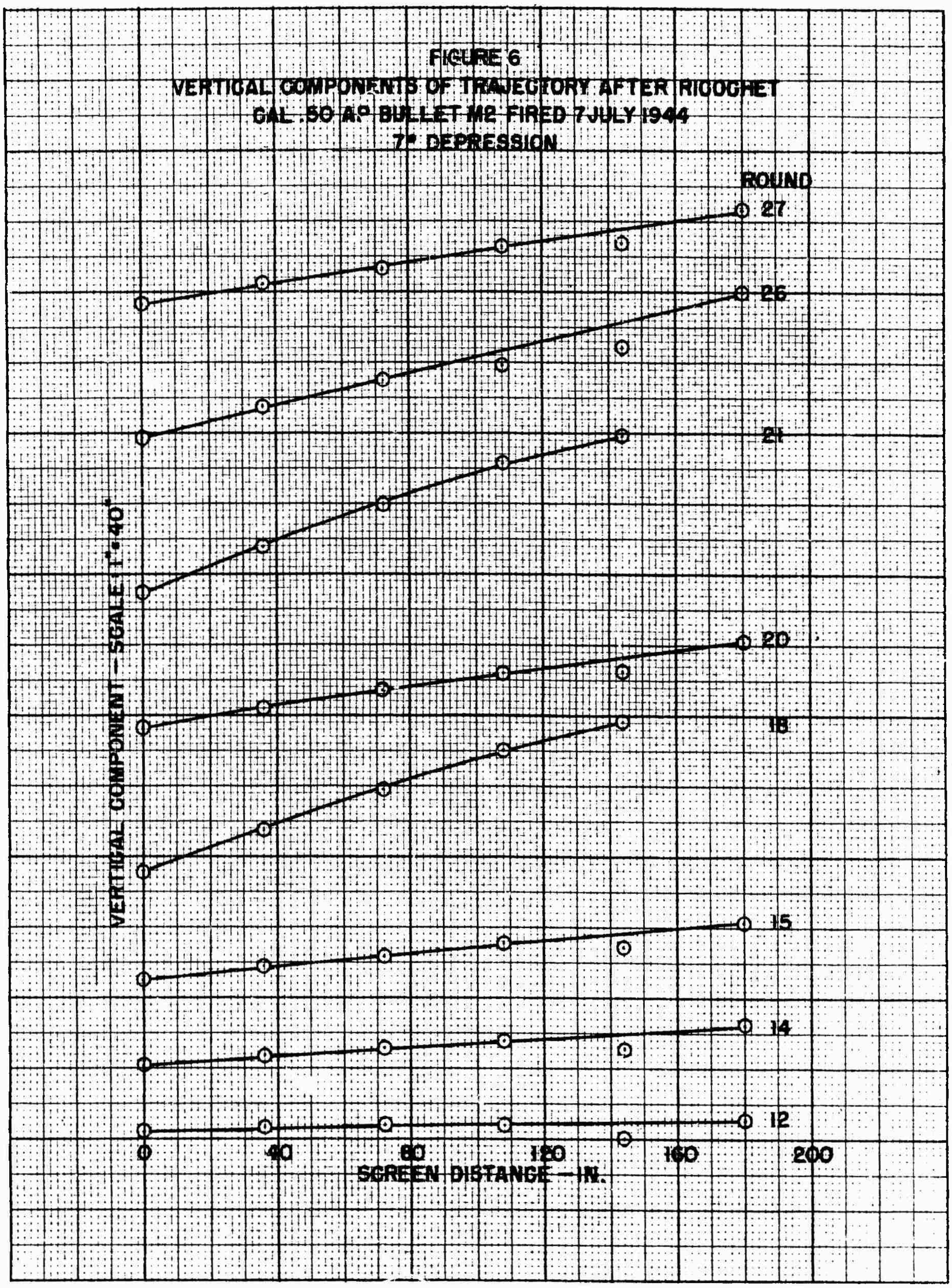


FIGURE 6
VERTICAL COMPONENTS OF TRAJECTORY AFTER RICOCHET
CAL .50 AP BULLET M2 FIRED 7 JULY 1944
7° DEPRESSION
ROUND
27
26
21
20
18
15
14
12
VERTICAL COMPONENT — SCALE 1"=40"
0
40
80
120
160
200
SCREEN DISTANCE — IN.

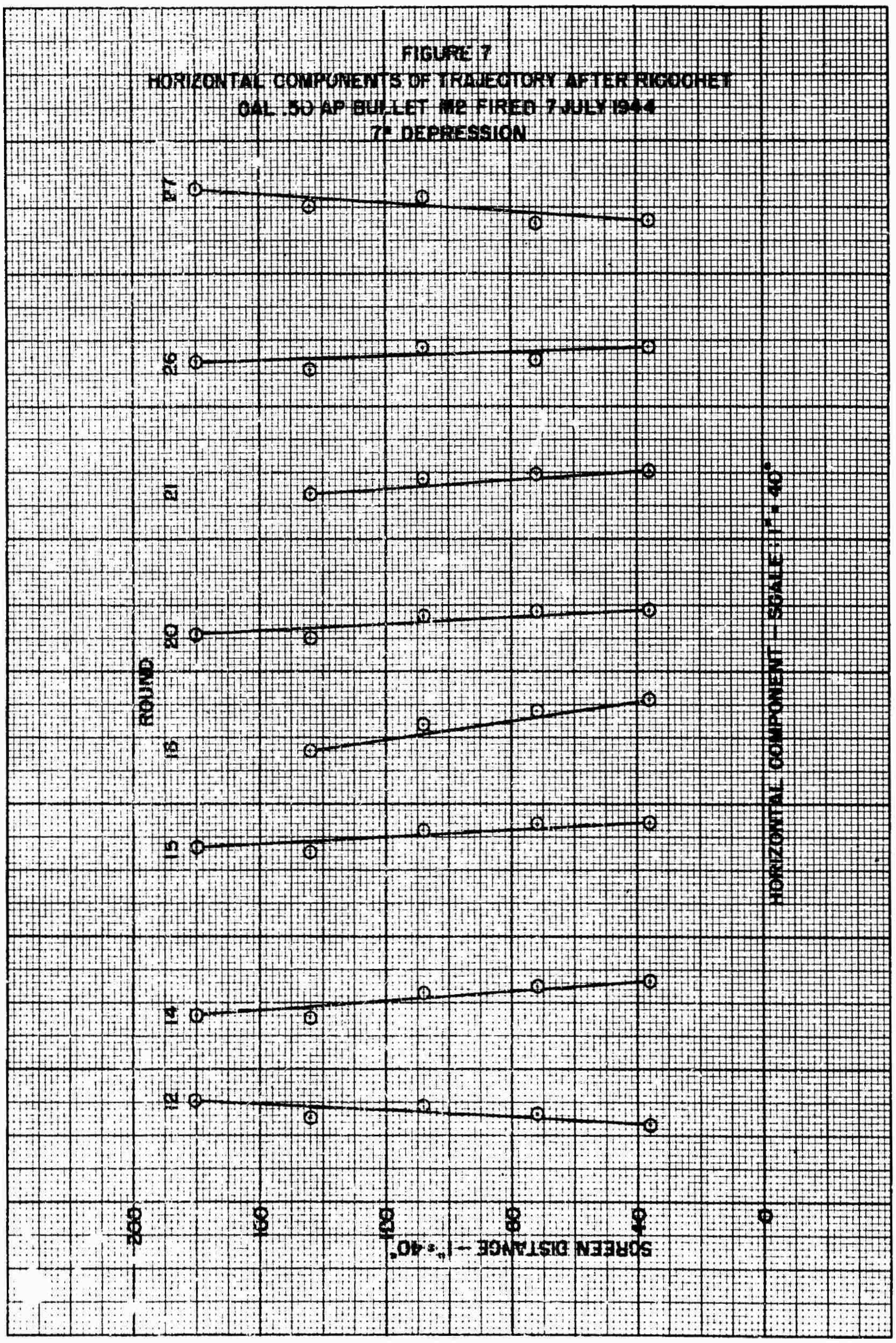


FIGURE 7
HORIZONTAL COMPONENTS OF TRAJECTORY AFTER RICOCHET
CAL .50 AP BULLET M2 FIRED 7 JULY 1944
7° DEPRESSION

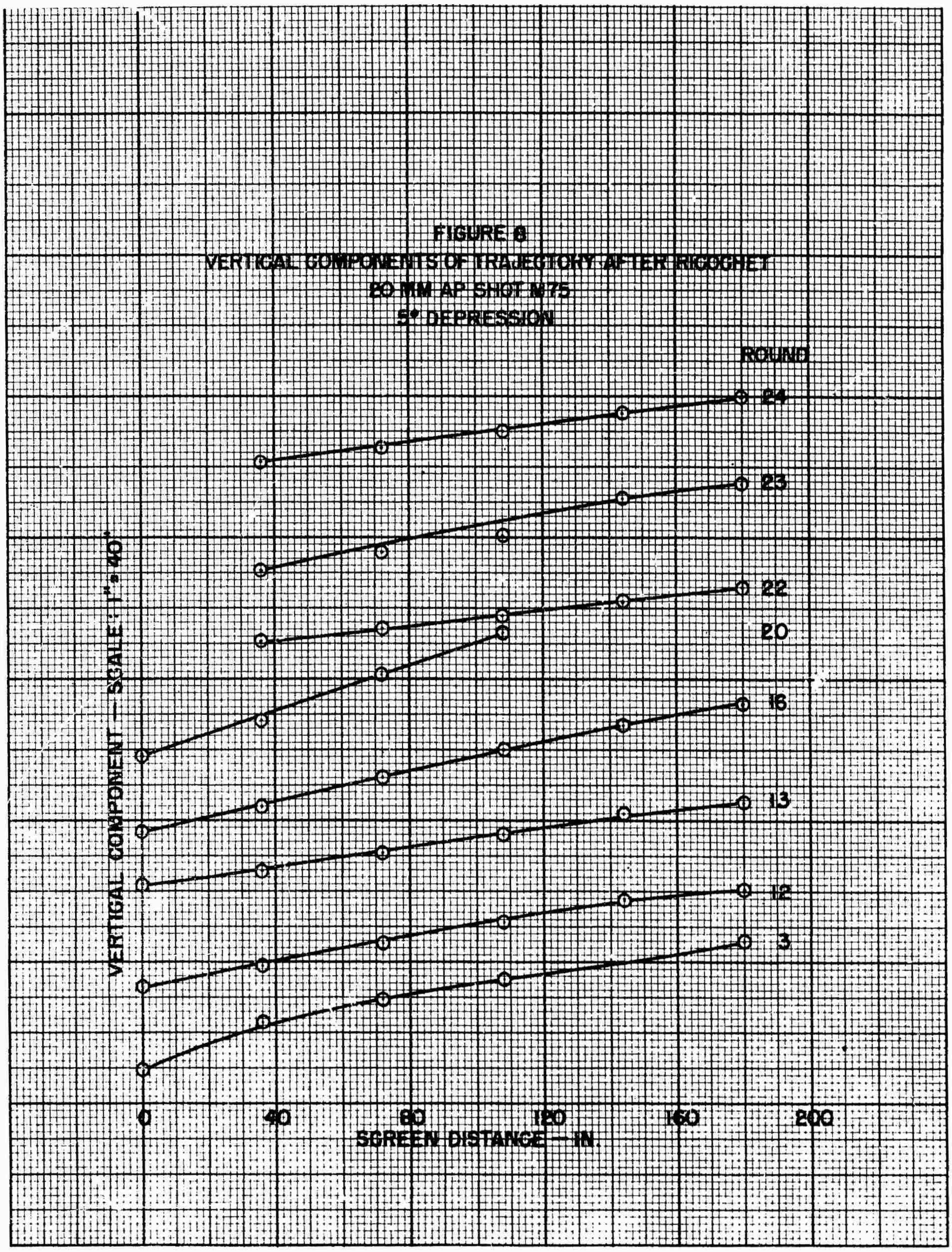


FIGURE 8
VERTICAL COMPONENTS OF TRAJECTORY AFTER RICOCHET
20 MM AP SHOT M75
5° DEPRESSION
ROUND
24
23
22
20
16
13
12
3
VERTICAL COMPONENT — SCALE : 1" = 40"
0
40
80
120
160
200
SCREEN DISTANCE — IN.

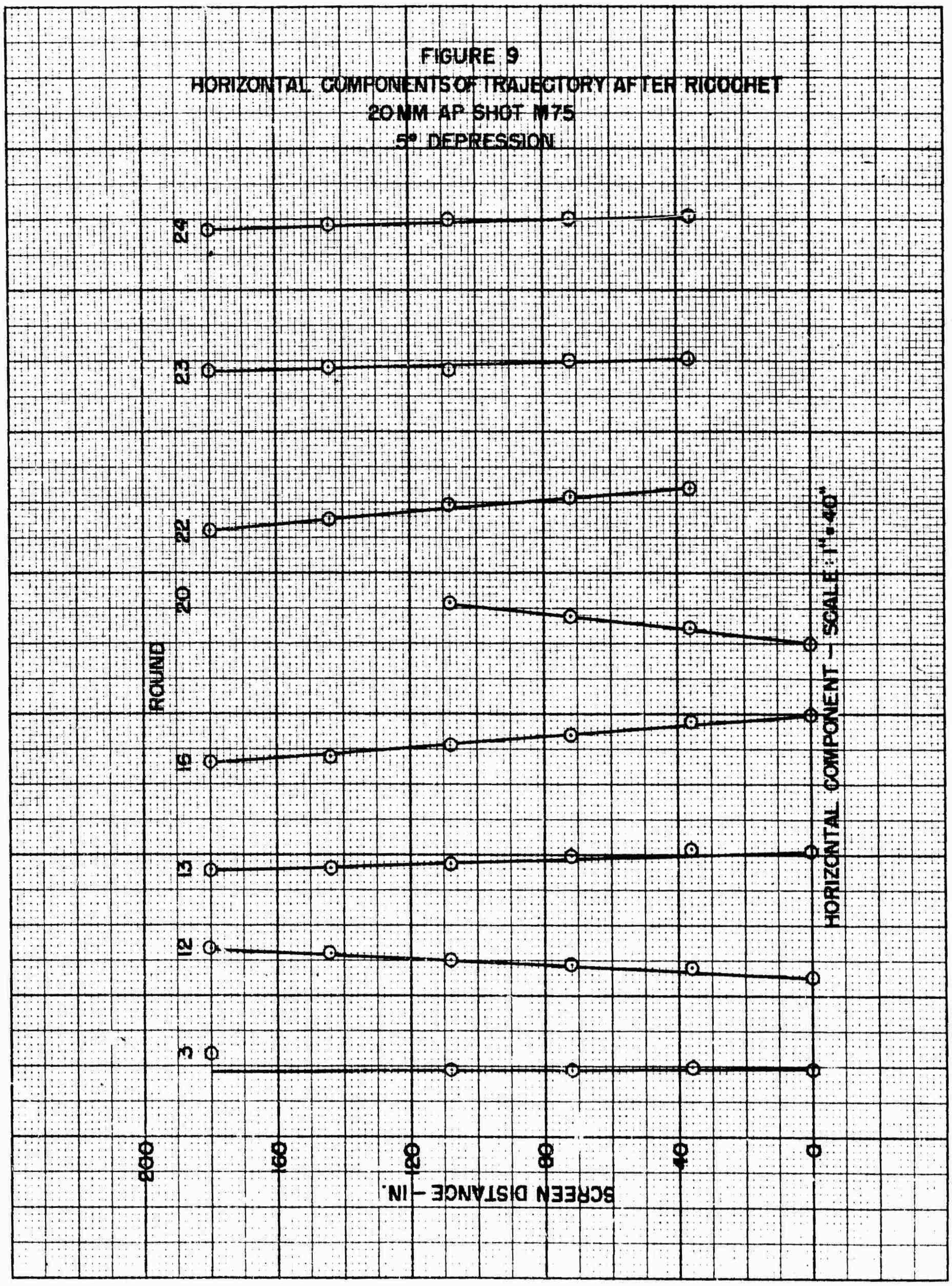


FIGURE 9
HORIZONTAL COMPONENTS OF TRAJECTORY AFTER RICOCHET
20 MM AP SHOT M75
5° DEPRESSION

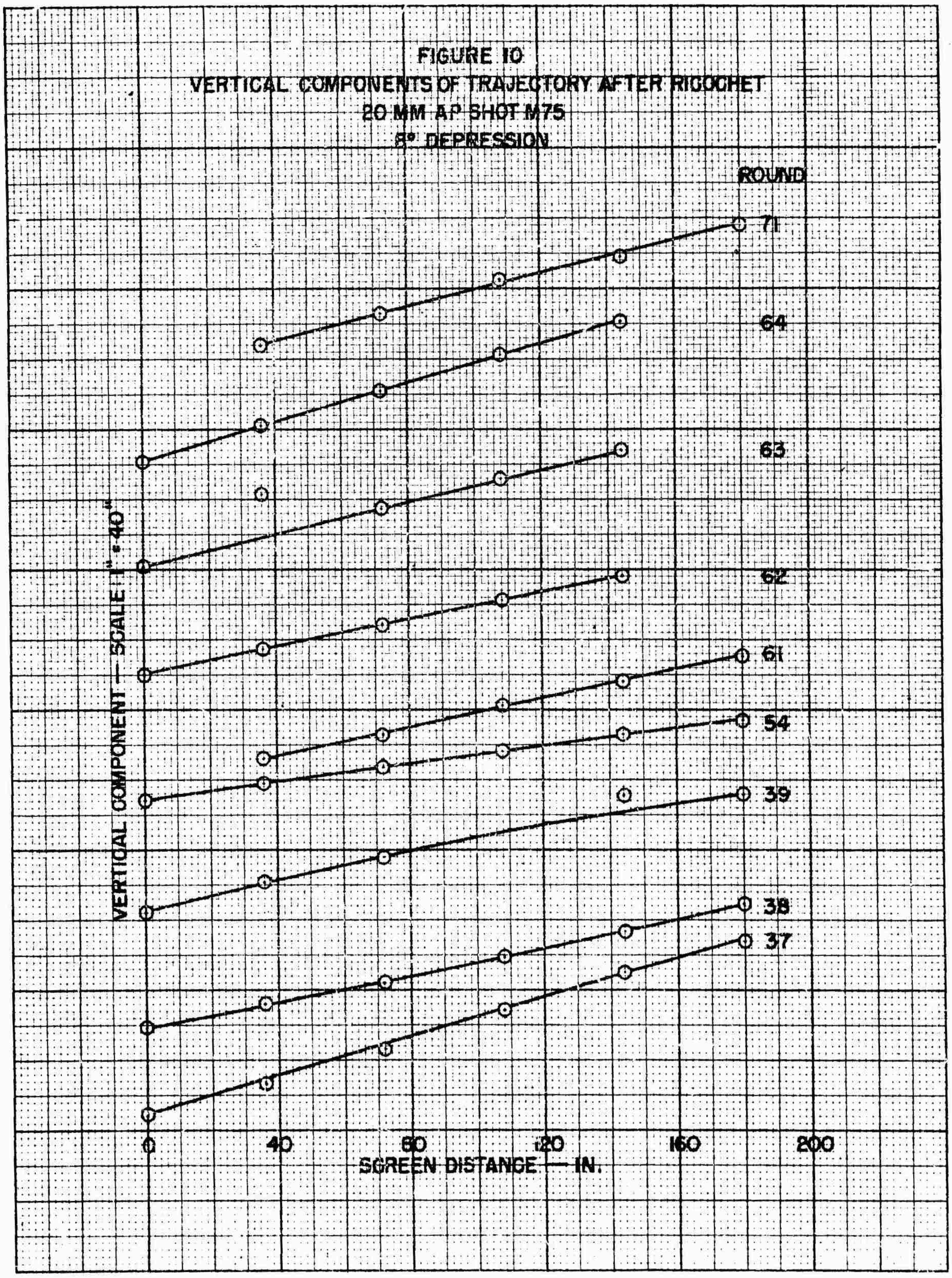


FIGURE 10
VERTICAL COMPONENTS OF TRAJECTORY AFTER RICOCHET
20 MM AP SHOT M75
8° DEPRESSION
ROUND
71
64
63
62
61
54
39
38
37
VERTICAL COMPONENT — SCALE 1" = 40"
0
40
80
120
160
200
SCREEN DISTANCE — IN.

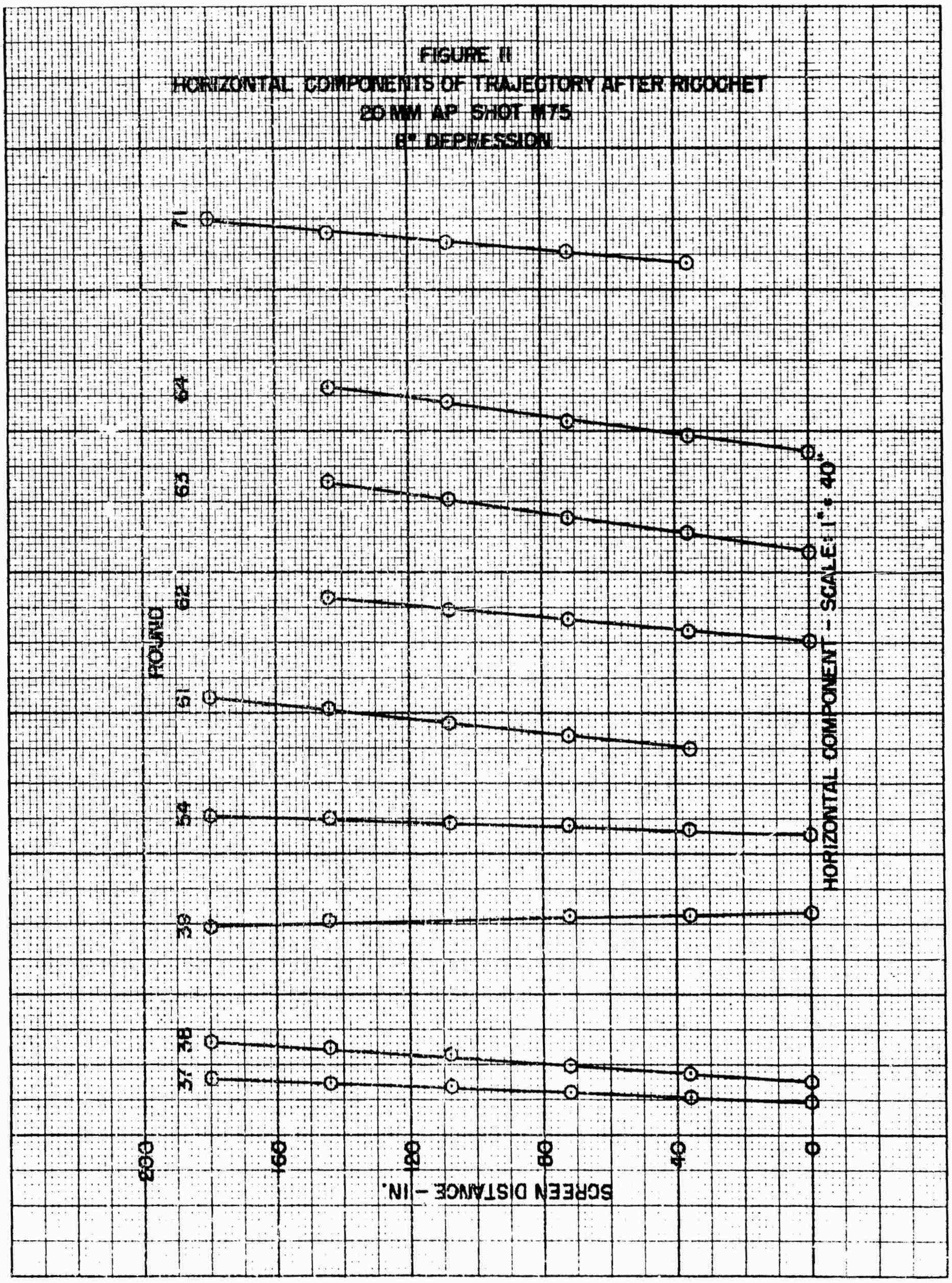


FIGURE II
HORIZONTAL COMPONENTS OF TRAJECTORY AFTER RICOCHET
20 MM AP SHOT M75
8° DEPRESSION

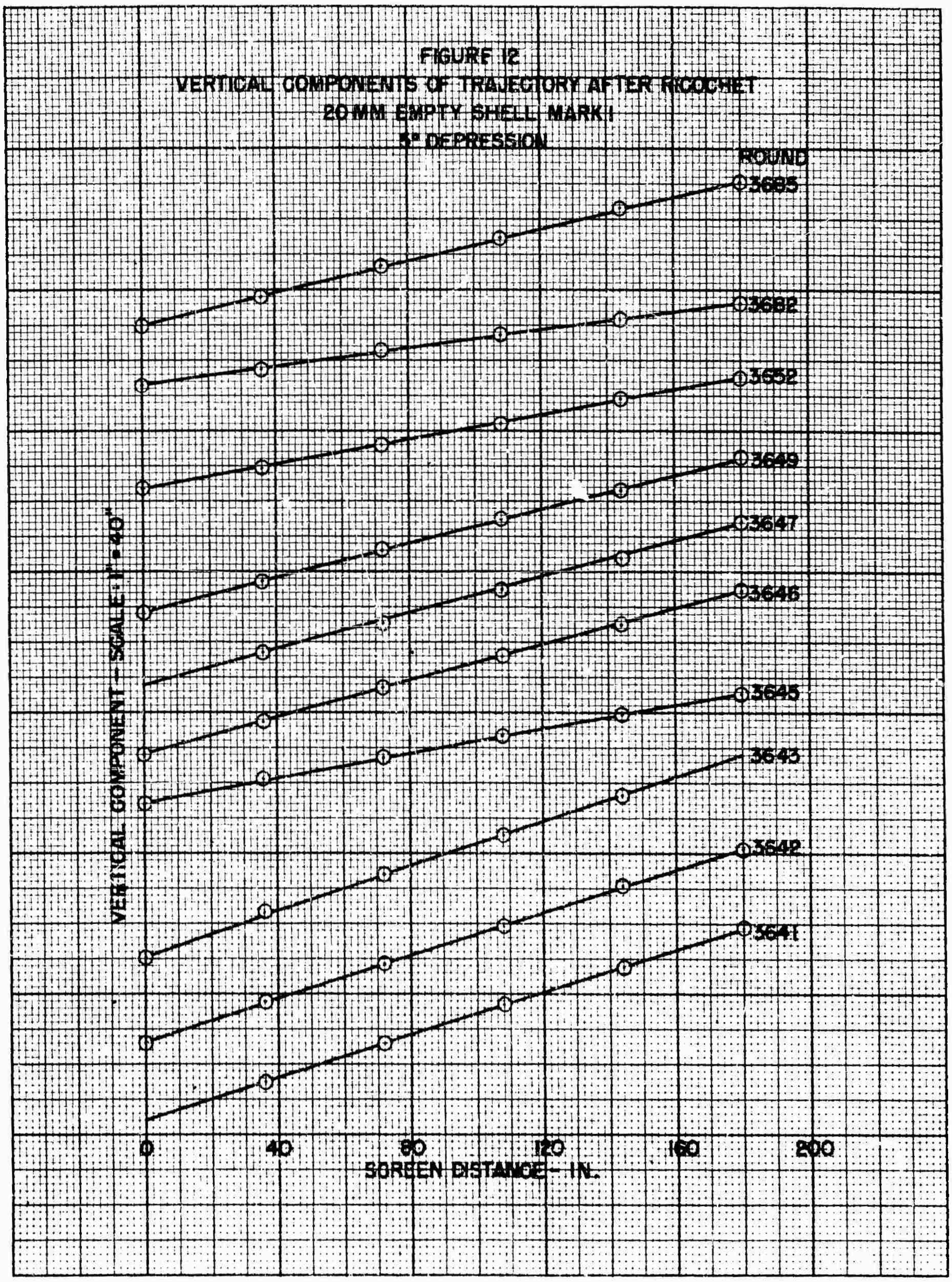


FIGURE 12
VERTICAL COMPONENTS OF TRAJECTORY AFTER RICOCHET
20 MM EMPTY SHELL MARK I
5° DEPRESSION
ROUND
3685
3682
3652
3649
3647
3646
3645
3643
3642
3641
VERTICAL COMPONENT - SCALE: 1" = 40"
0
40
80
120
160
200
SCREEN DISTANCE - IN.

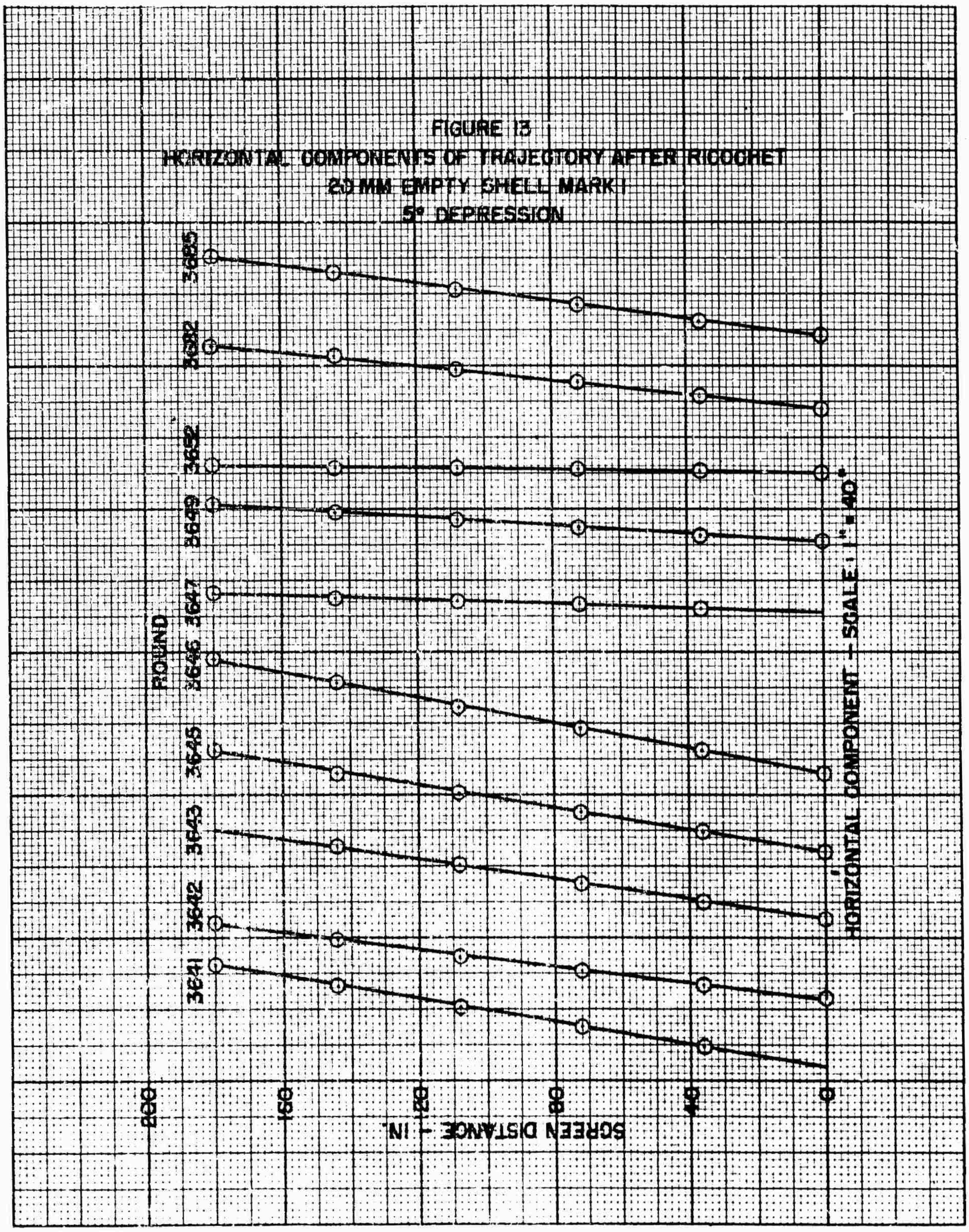


FIGURE 13
HORIZONTAL COMPONENTS OF TRAJECTORY AFTER RICOCHET
20 MM EMPTY SHELL MARK I
5° DEPRESSION

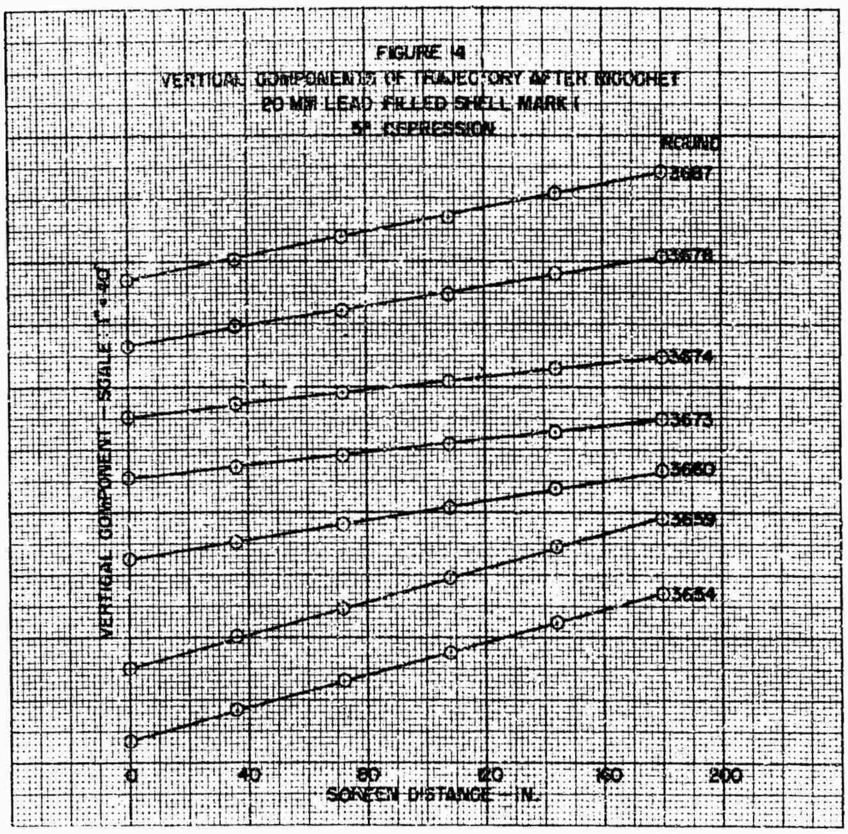


FIGURE 14
VERTICAL COMPONENTS OF TRAJECTORY AFTER RICOCHET
20 MM LEAD FILLED SHELL MARK I
5° DEPRESSION

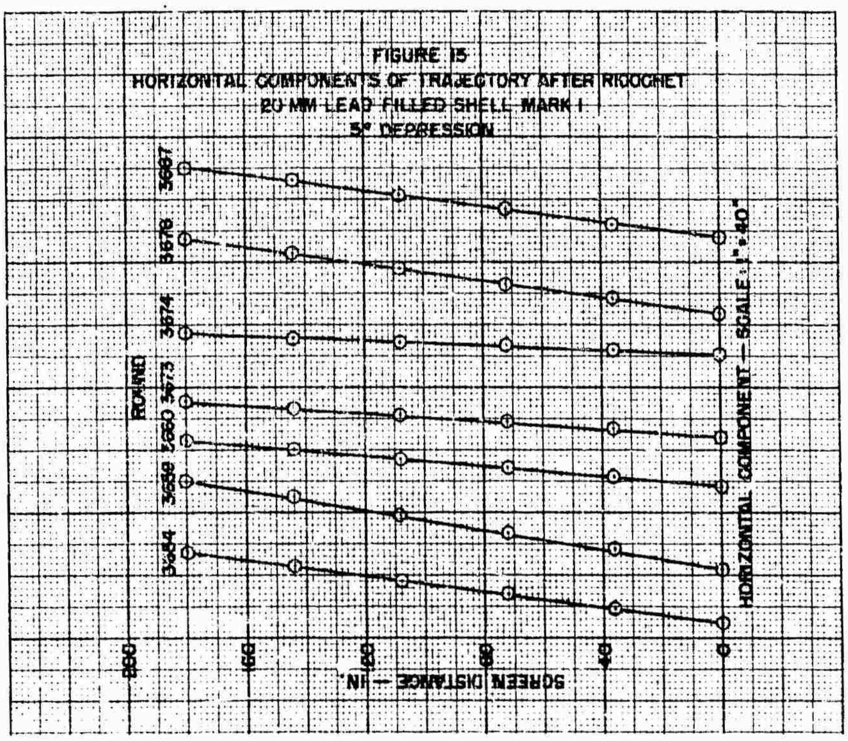


FIGURE 15
HORIZONTAL COMPONENTS OF TRAJECTORY AFTER RICOCHET
20 MM LEAD FILLED SHELL MARK I
5° DEPRESSION

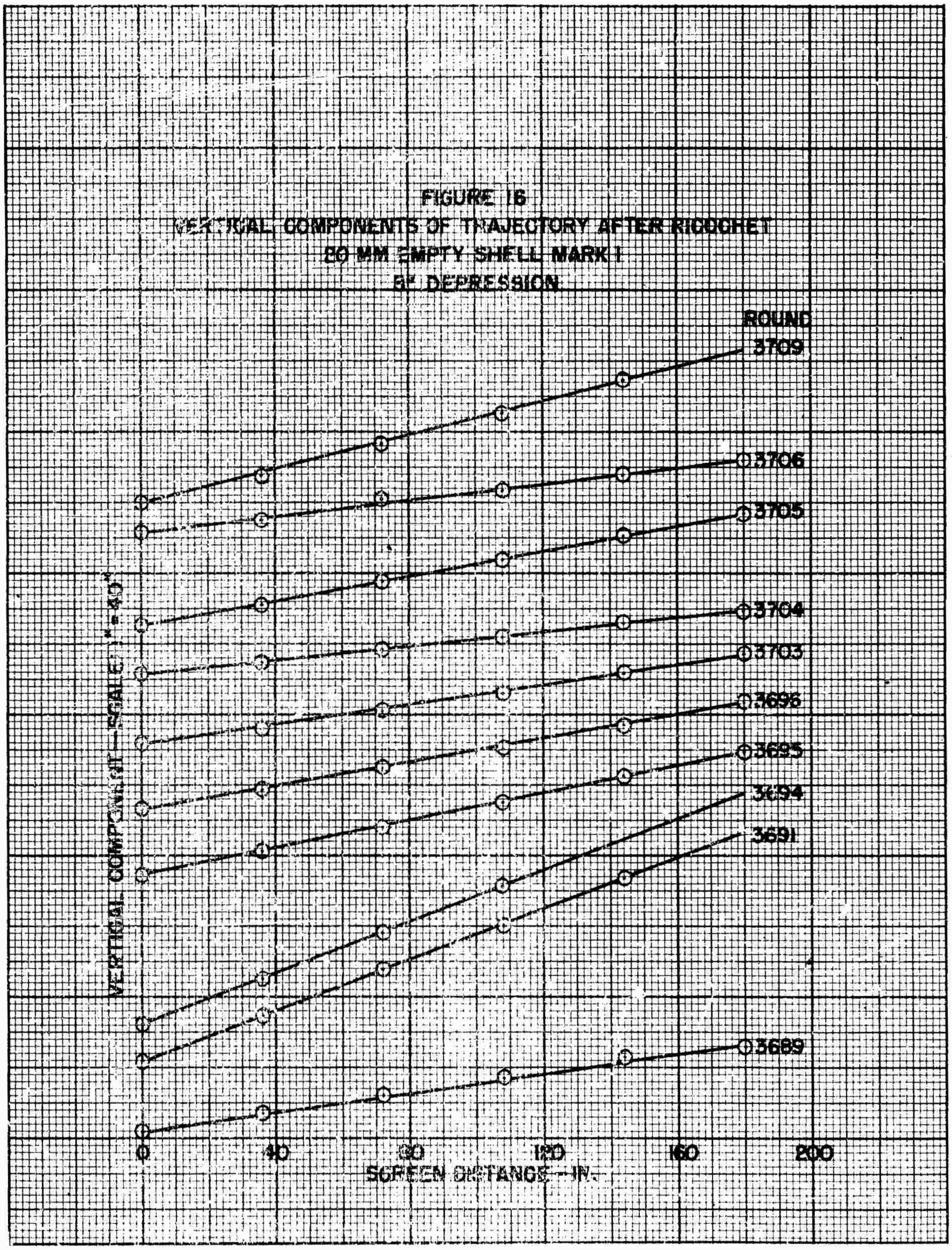


FIGURE 16
VERTICAL COMPONENTS OF TRAJECTORY AFTER RICOCHET
20 MM EMPTY SHELL MARK I
5° DEPRESSION
ROUND
3709
3706
3705
3704
3703
3696
3695
3694
3691
3689
0
40
80
120
160
200
SCREEN DISTANCE — IN.

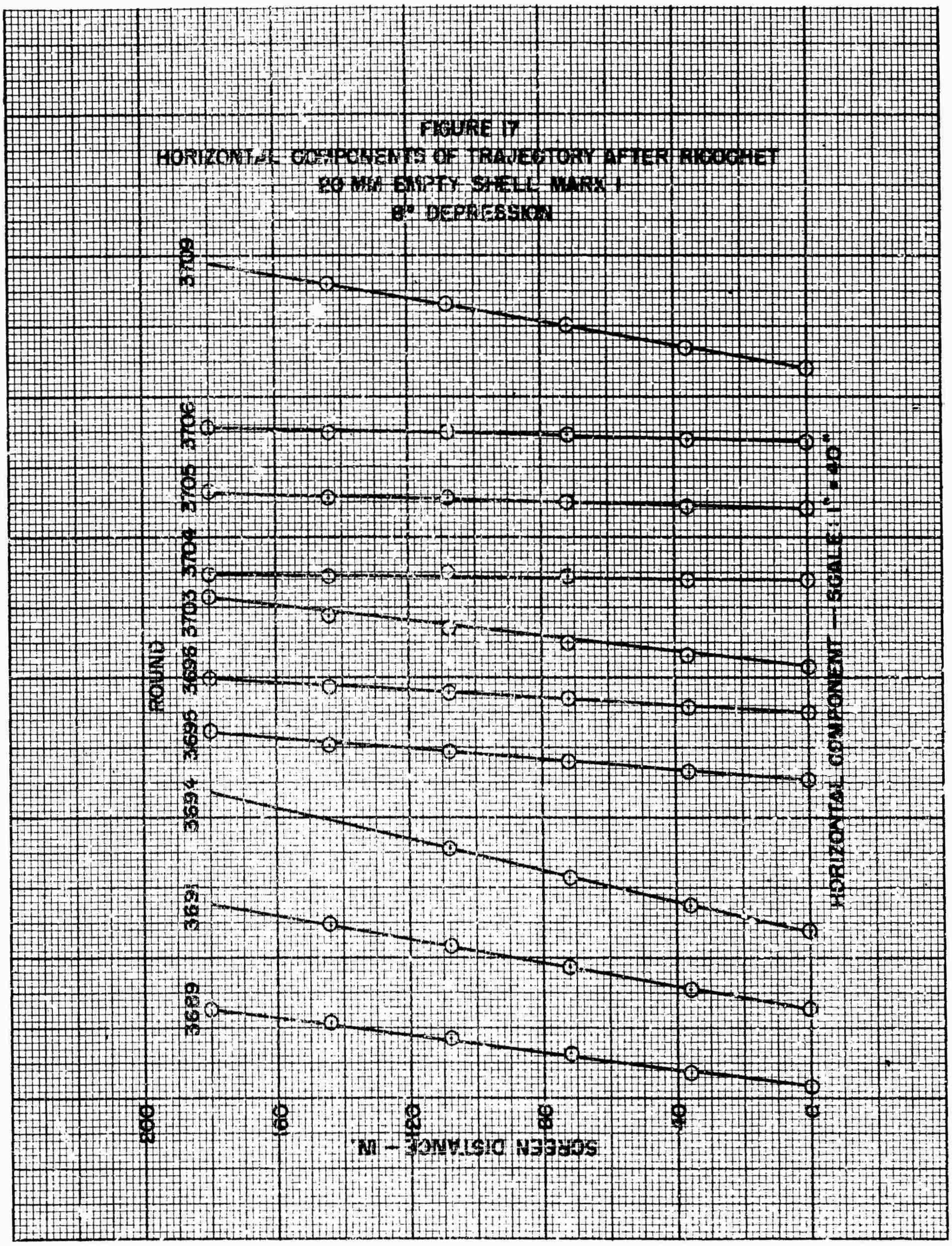


FIGURE 17
HORIZONTAL COMPONENTS OF TRAJECTORY AFTER RICOCHET
20 MM EMPTY SHELL MARK I
8° DEPRESSION

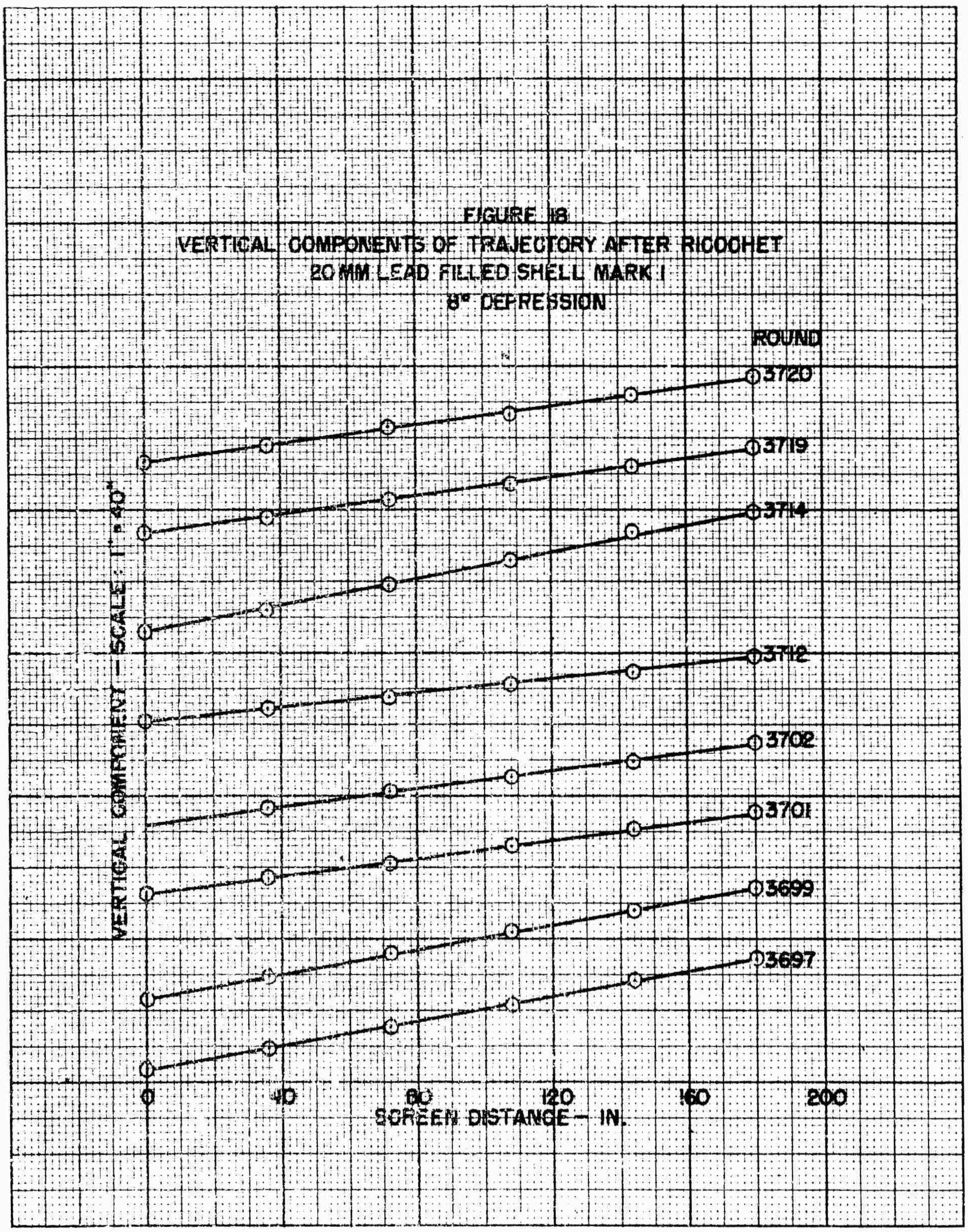


FIGURE 18
VERTICAL COMPONENTS OF TRAJECTORY AFTER RICOCHET
20 MM LEAD FILLED SHELL MARK I
8° DEPRESSION
ROUND
3720
3719
3714
3712
3702
3701
3699
3697
VERTICAL COMPONENT — SCALE: 1" = 40"
0
40
80
120
160
200
SCREEN DISTANCE — IN.

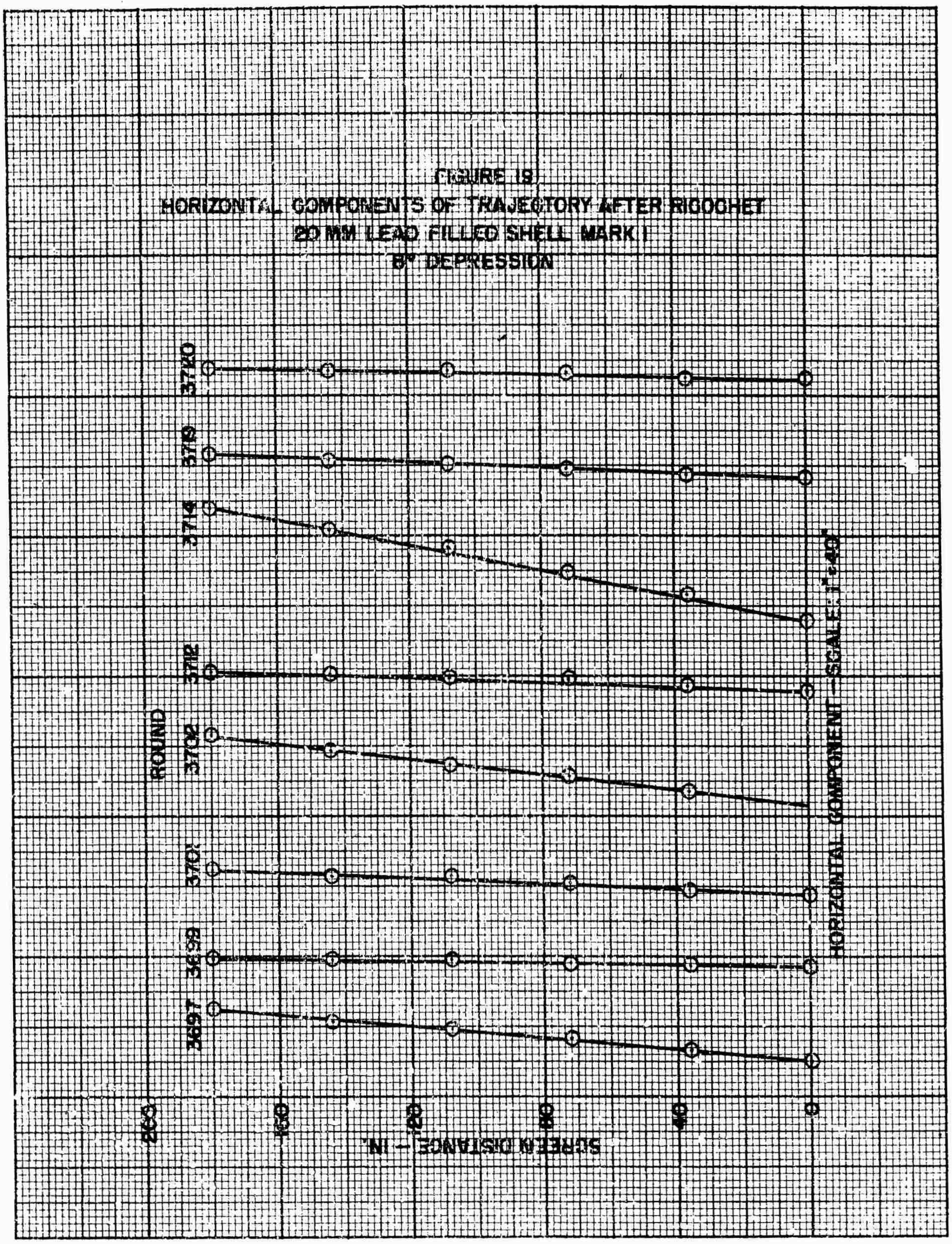


FIGURE 19
HORIZONTAL COMPONENTS OF TRAJECTORY AFTER RICOCHET
20 MM LEAD FILLED SHELL MARK I
8° DEPRESSION

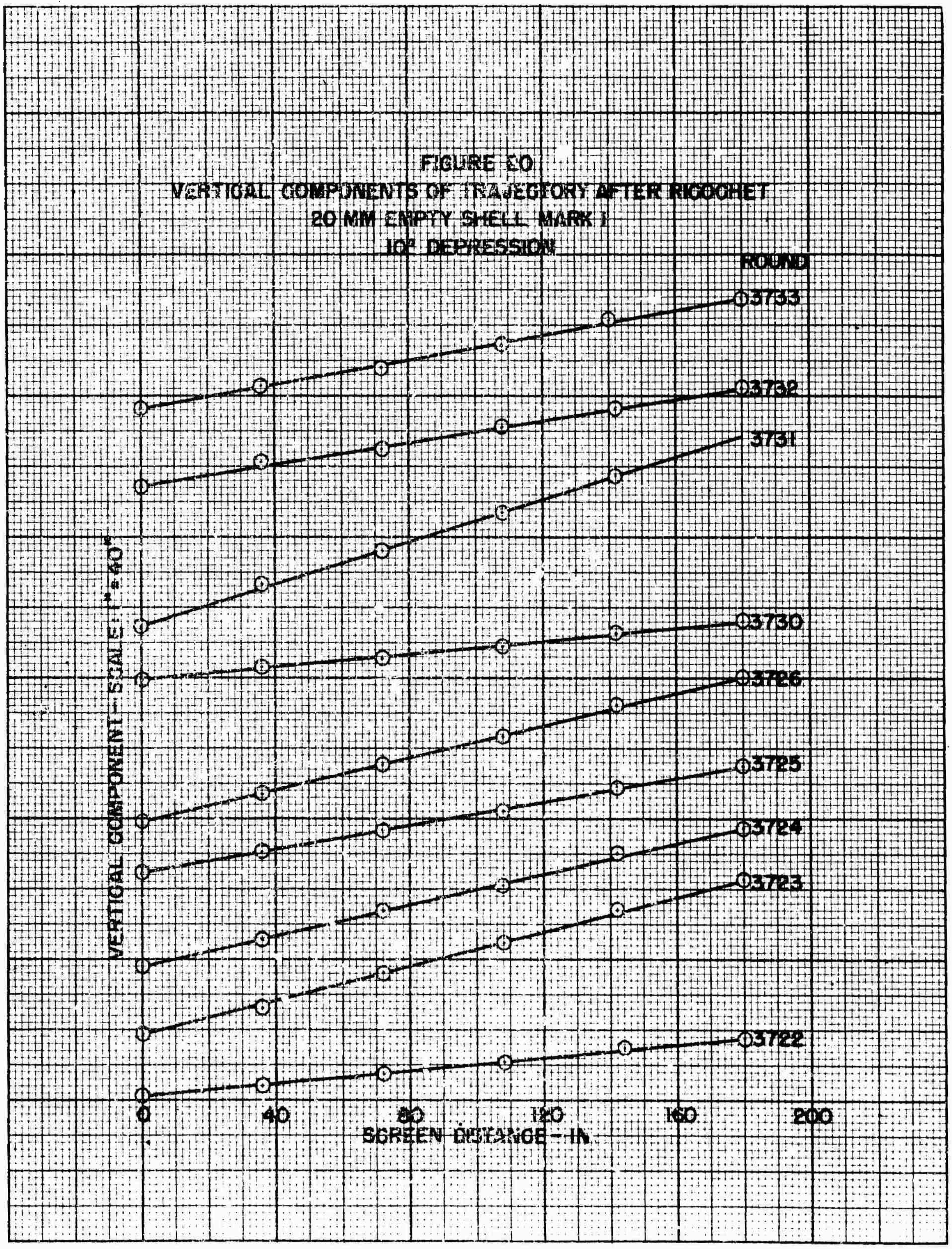
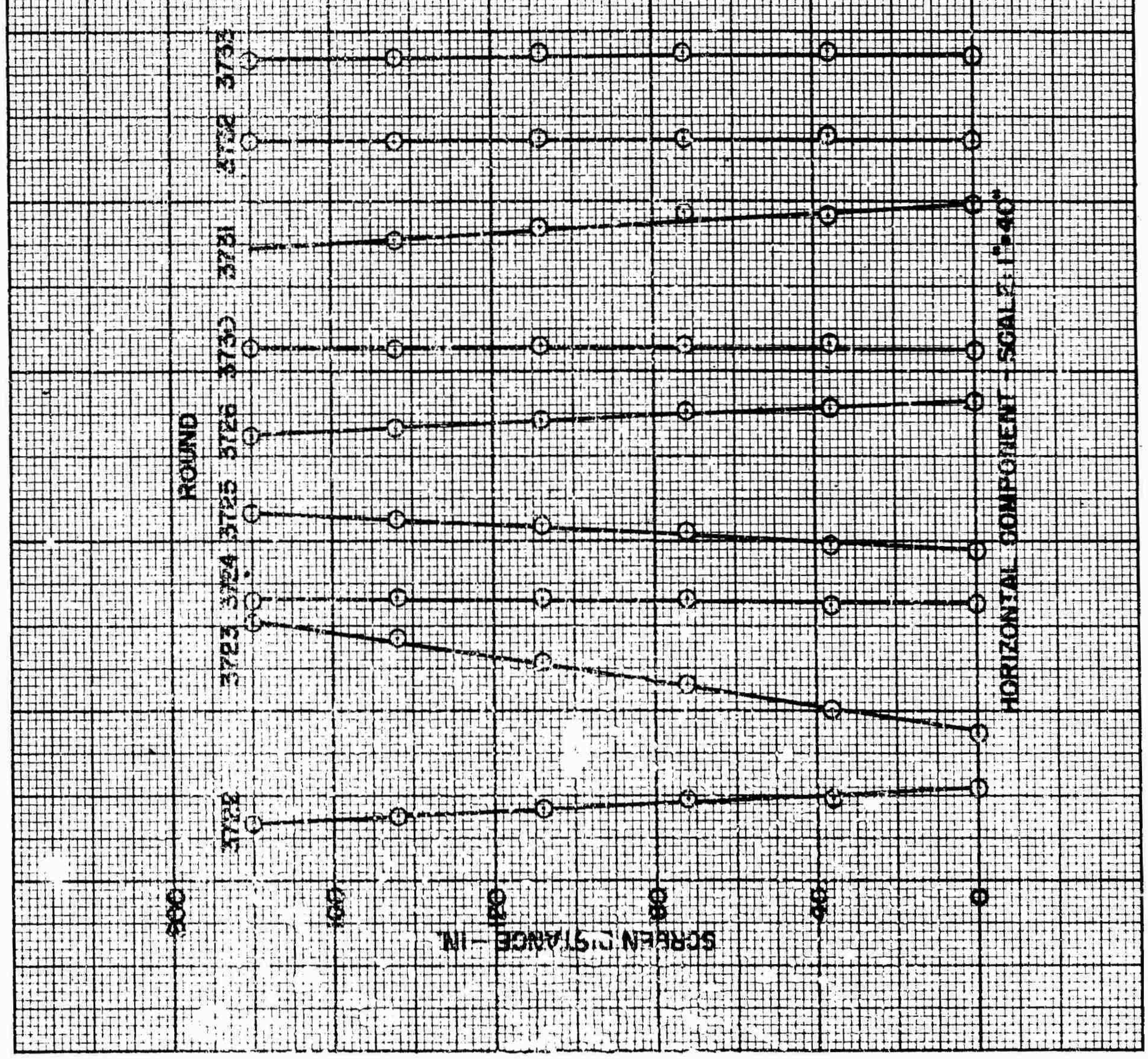


FIGURE 50
VERTICAL COMPONENTS OF TRAJECTORY AFTER RICOCHET
20 MM EMPTY SHELL MARK I
10° DEPRESSION

FIGURE 21
HORIZONTAL COMPONENTS OF TRAJECTORY AFTER RICOCHET
20 MM EMPTY SHELL MARK I
10° DEPRESSION



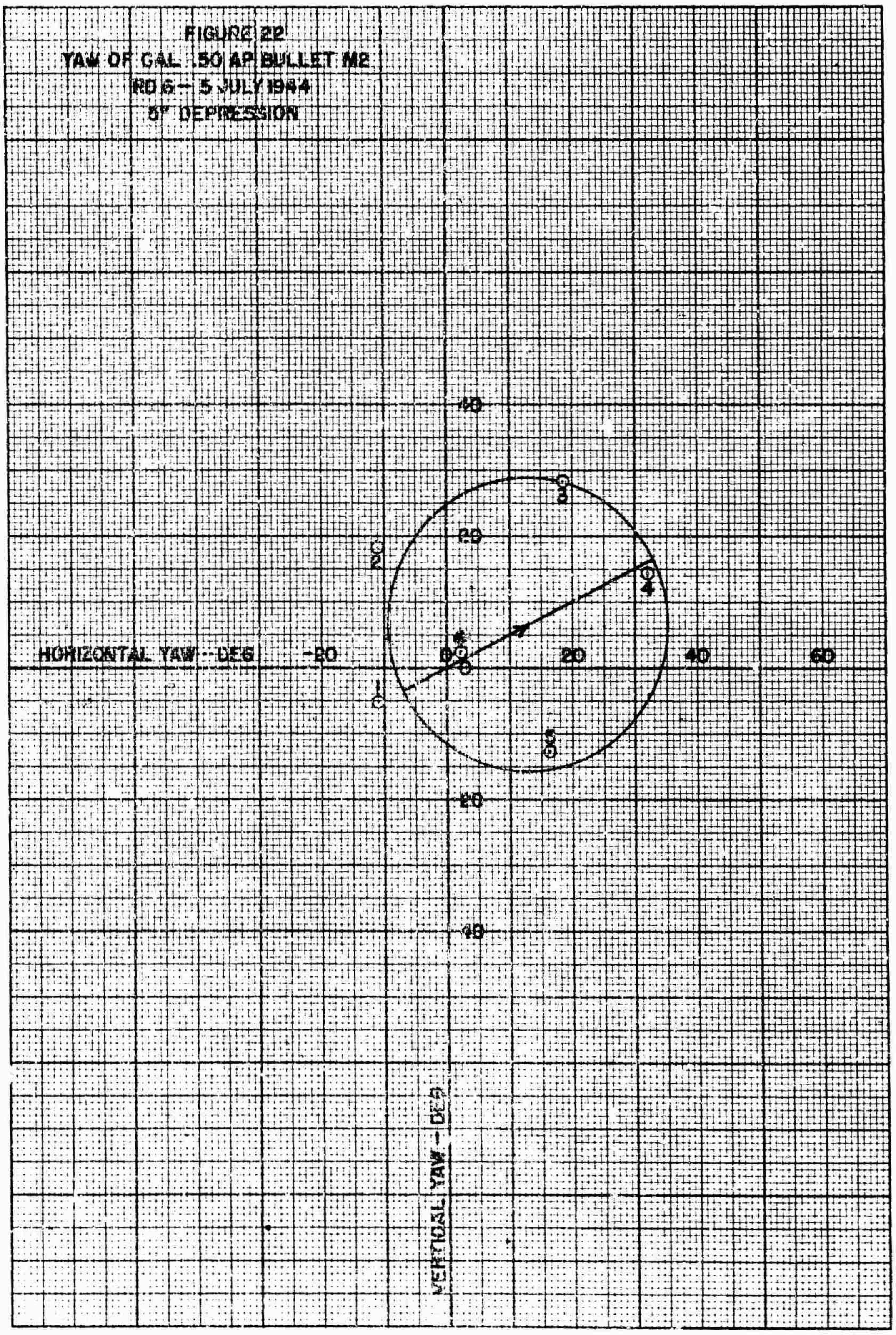


FIGURE 22
YAW OF CAL .50 AP BULLET M2
RD 6 — 5 JULY 1944
5° DEPRESSION
HORIZONTAL YAW – DEG
-20
0
20
40
60
40
20
-20
-40
VERTICAL YAW – DEG

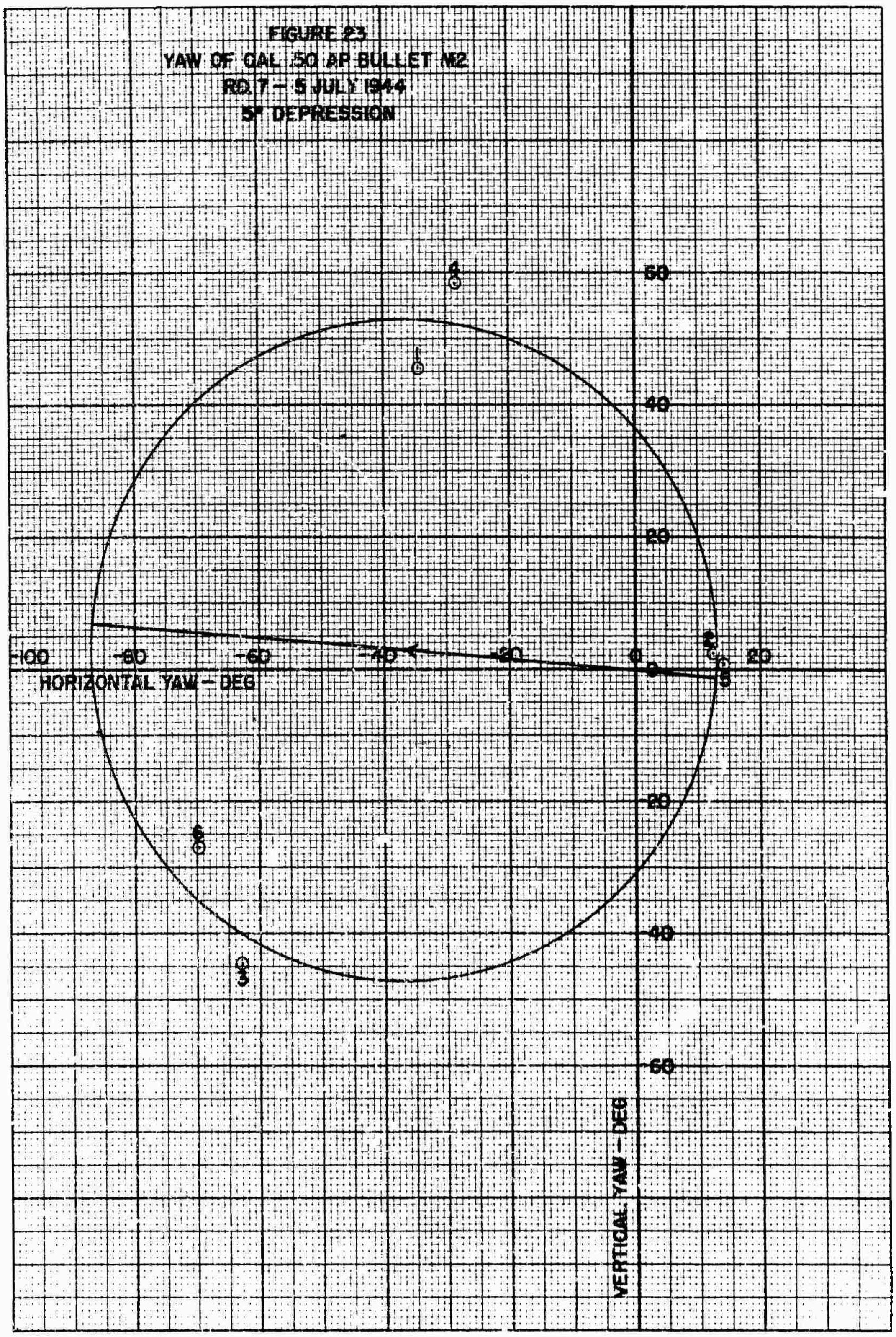


FIGURE 23
YAW OF CAL .50 AP BULLET M2
RD. 7 – 5 JULY 1944
5° DEPRESSION
HORIZONTAL YAW – DEG
VERTICAL YAW – DEG
-100
-80
-60
-40
-20
0
20
60
40
20
20
40
60

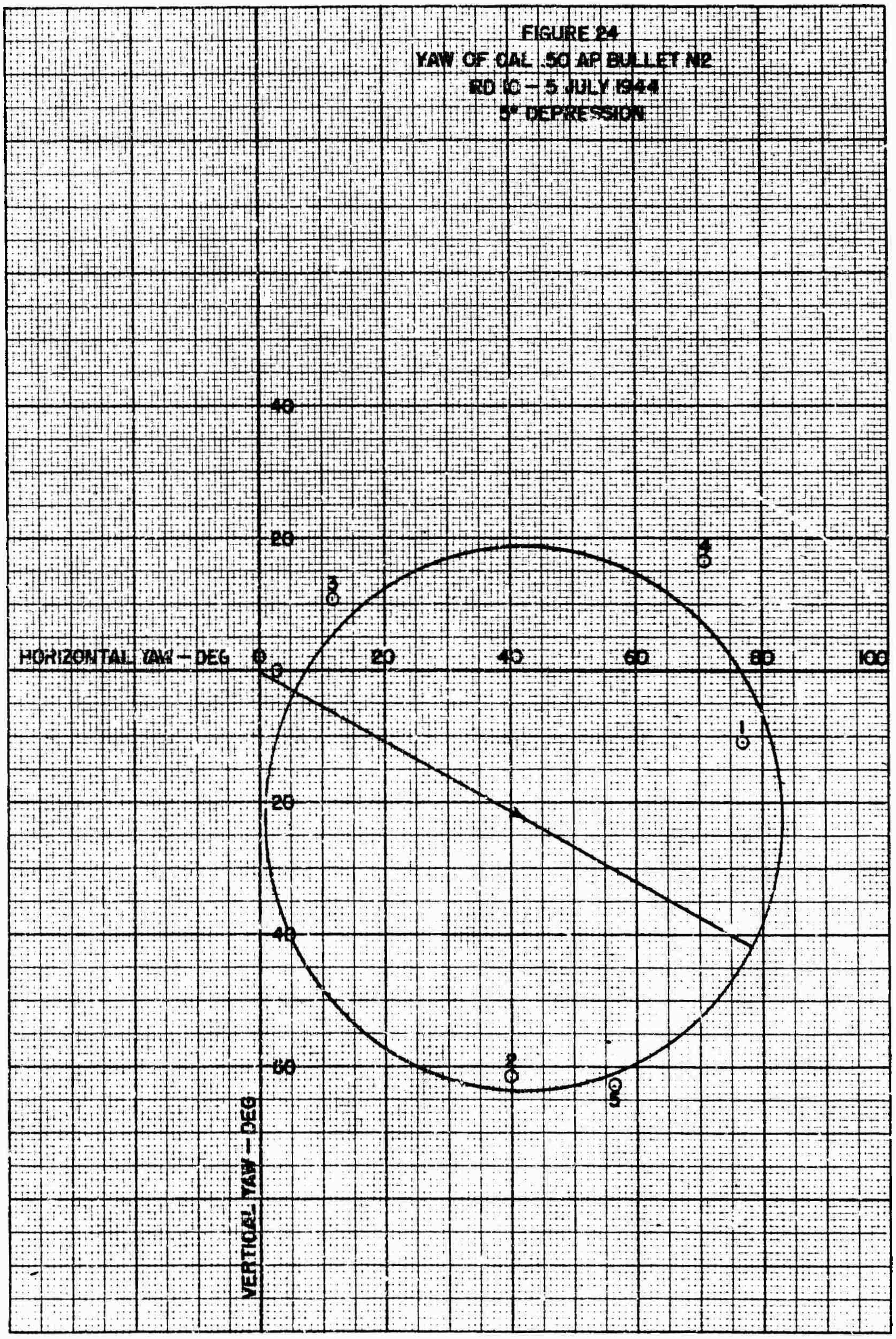


FIGURE 24
YAW OF CAL .50 AP BULLET M2
RD 10 - 5 JULY 1944
5° DEPRESSION
HORIZONTAL YAW - DEG
VERTICAL YAW - DEG
0
20
40
60
80
100
20
40
60
1
2
3
4
5

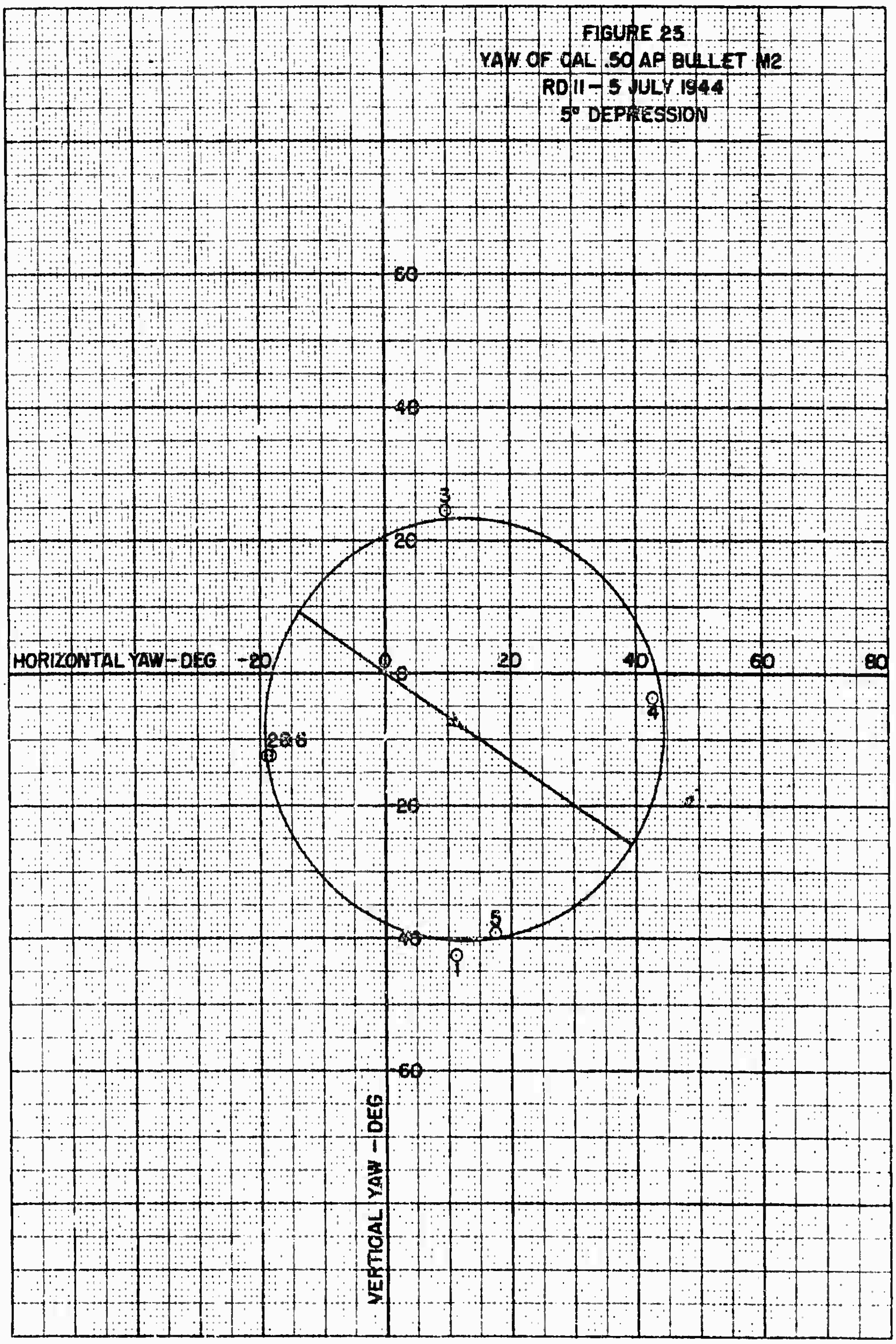


FIGURE 25
YAW OF CAL .50 AP BULLET M2
RD 11 – 5 JULY 1944
5° DEPRESSION
HORIZONTAL YAW – DEG
VERTICAL YAW – DEG
-20
0
20
40
60
80
60
40
20
20
40
60
3
4
2&6
5
1

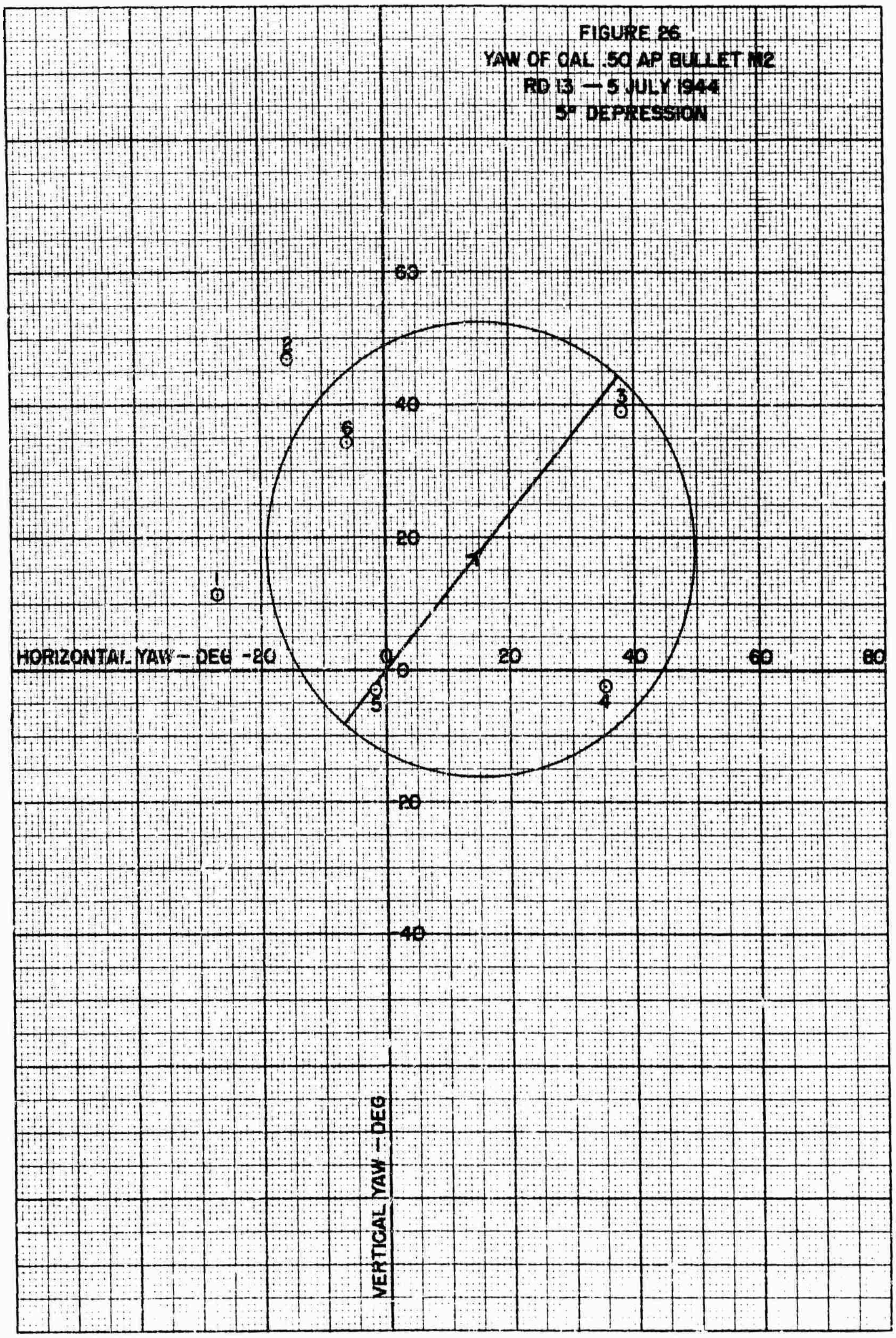


FIGURE 26
YAW OF CAL .50 AP BULLET M2
RD 13 — 5 JULY 1944
5° DEPRESSION
HORIZONTAL YAW — DEG
VERTICAL YAW — DEG
-20
0
20
40
60
80
60
40
20
-20
-40
1
2
3
4
5
6

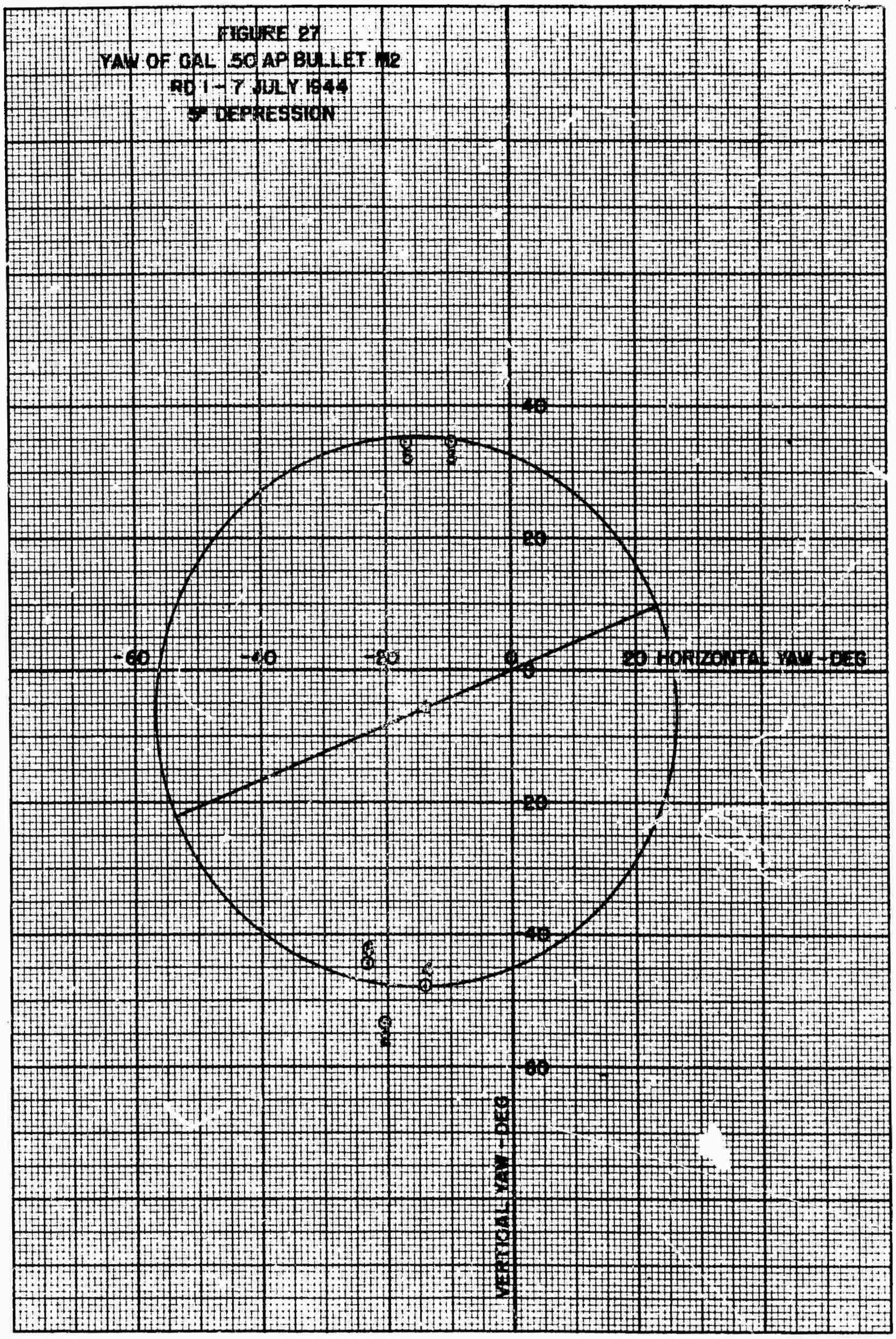


FIGURE 27
YAW OF CAL .50 AP BULLET M2
RD 1 - 7 JULY 1944
5° DEPRESSION
-60
-40
-20
0
20 HORIZONTAL YAW - DEG
40
20
20
40
60
VERTICAL YAW - DEG

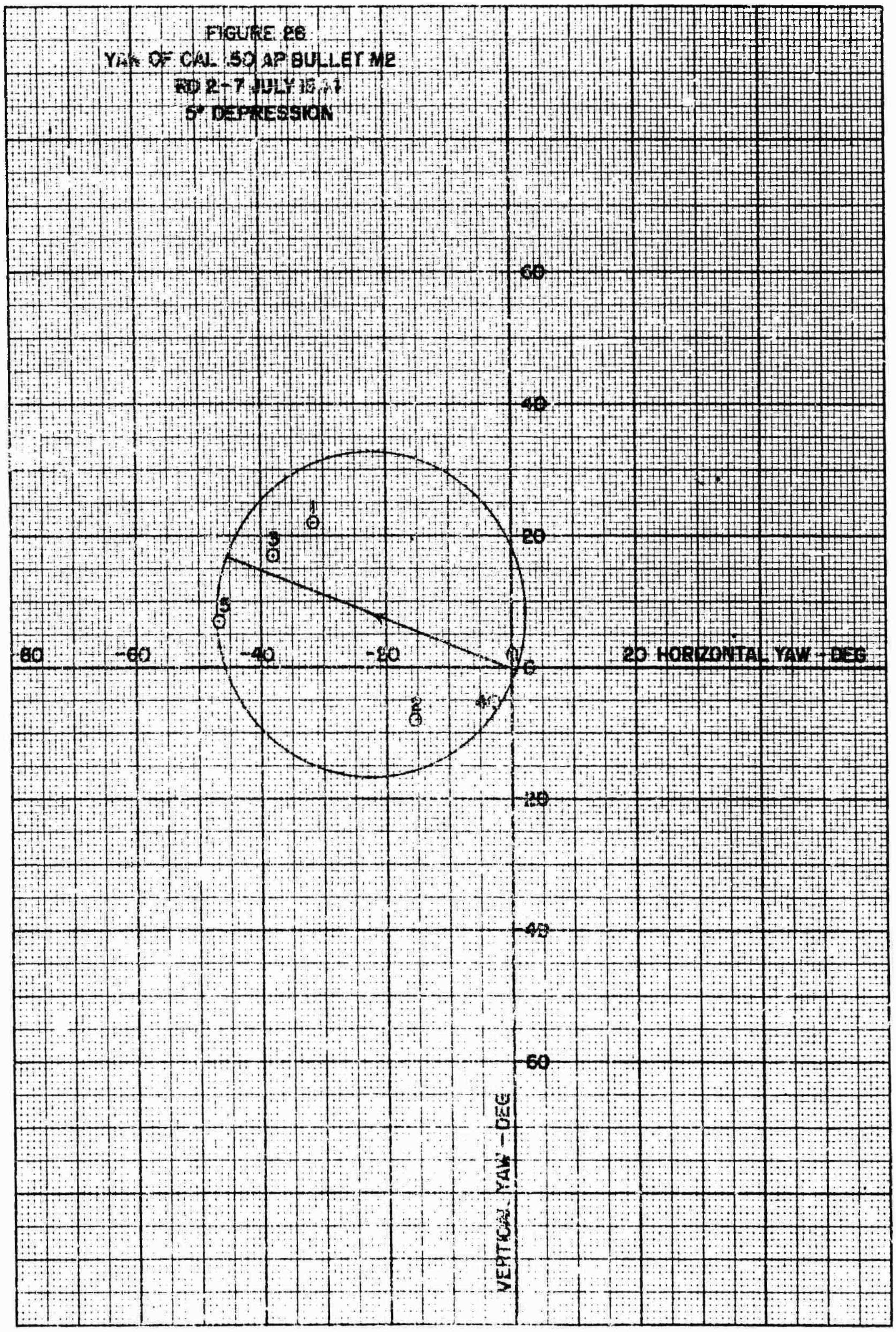


FIGURE 26
YAW OF CAL .50 AP BULLET M2
RD 2 - 7 JULY [illegible]
5° DEPRESSION

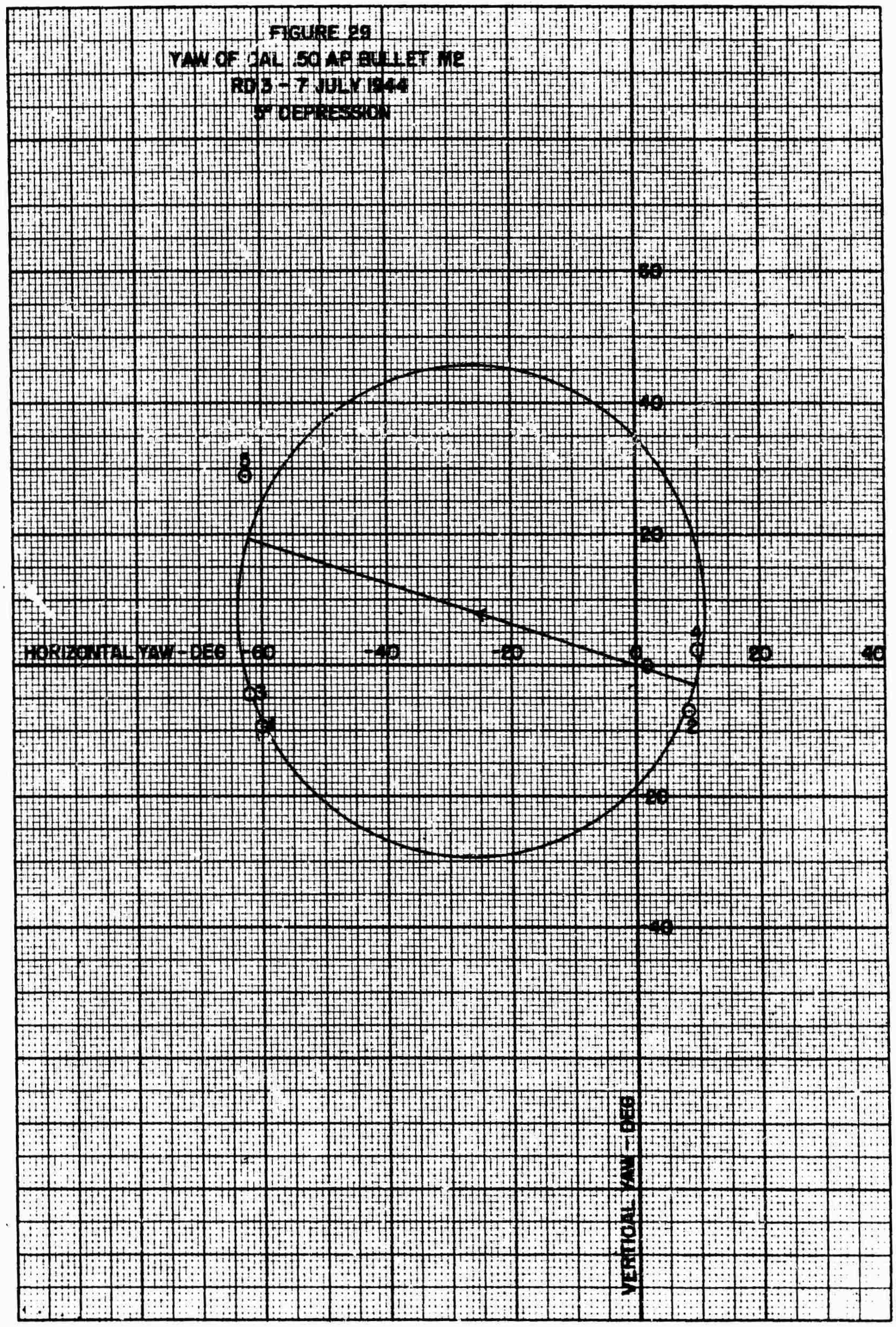
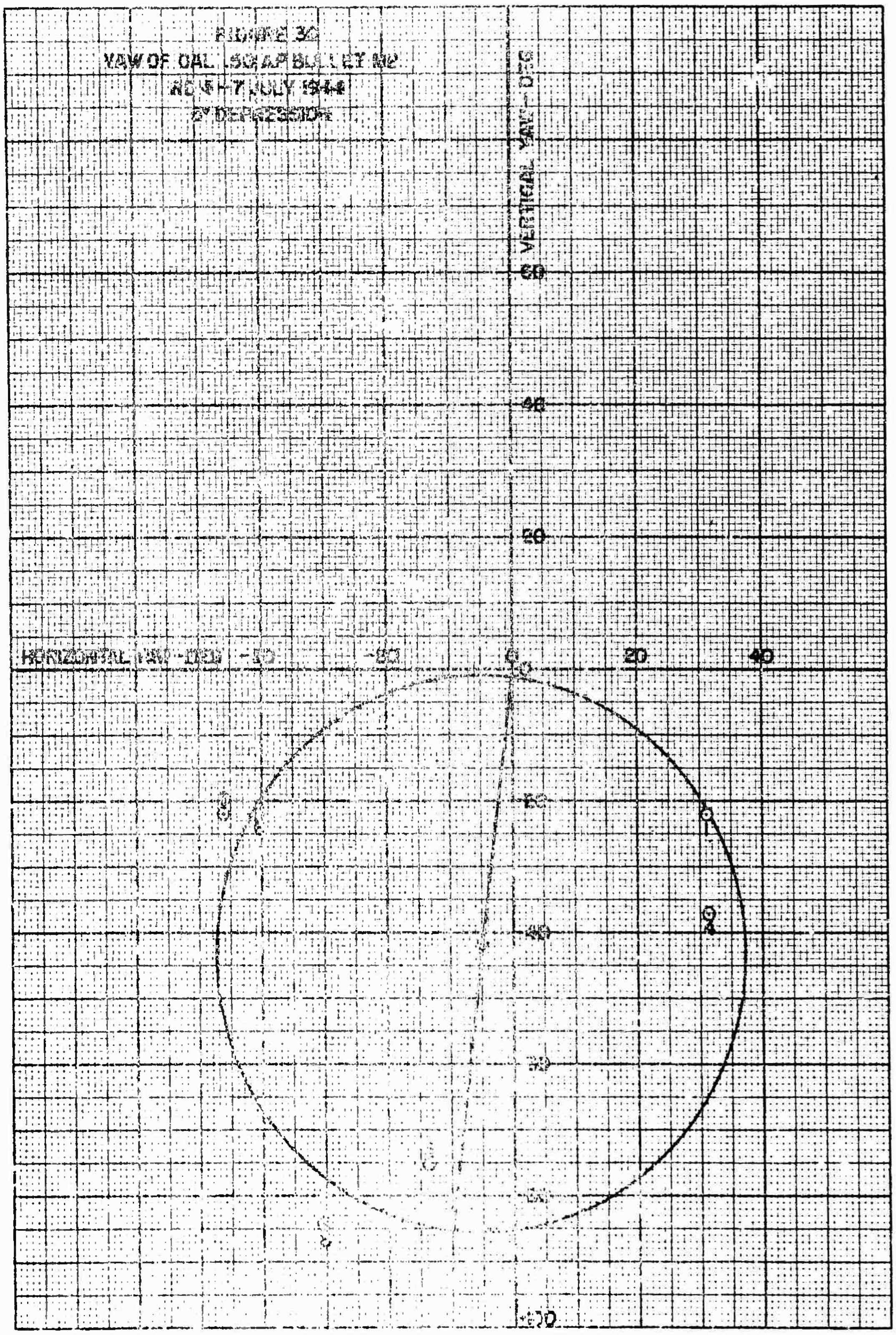


FIGURE 29
YAW OF CAL .50 AP BULLET M2
RD 3 - 7 JULY 1944
5° DEPRESSION


VERTICAL YAW - DEG
60
40
20
HORIZONTAL YAW - DEG
0
20
40

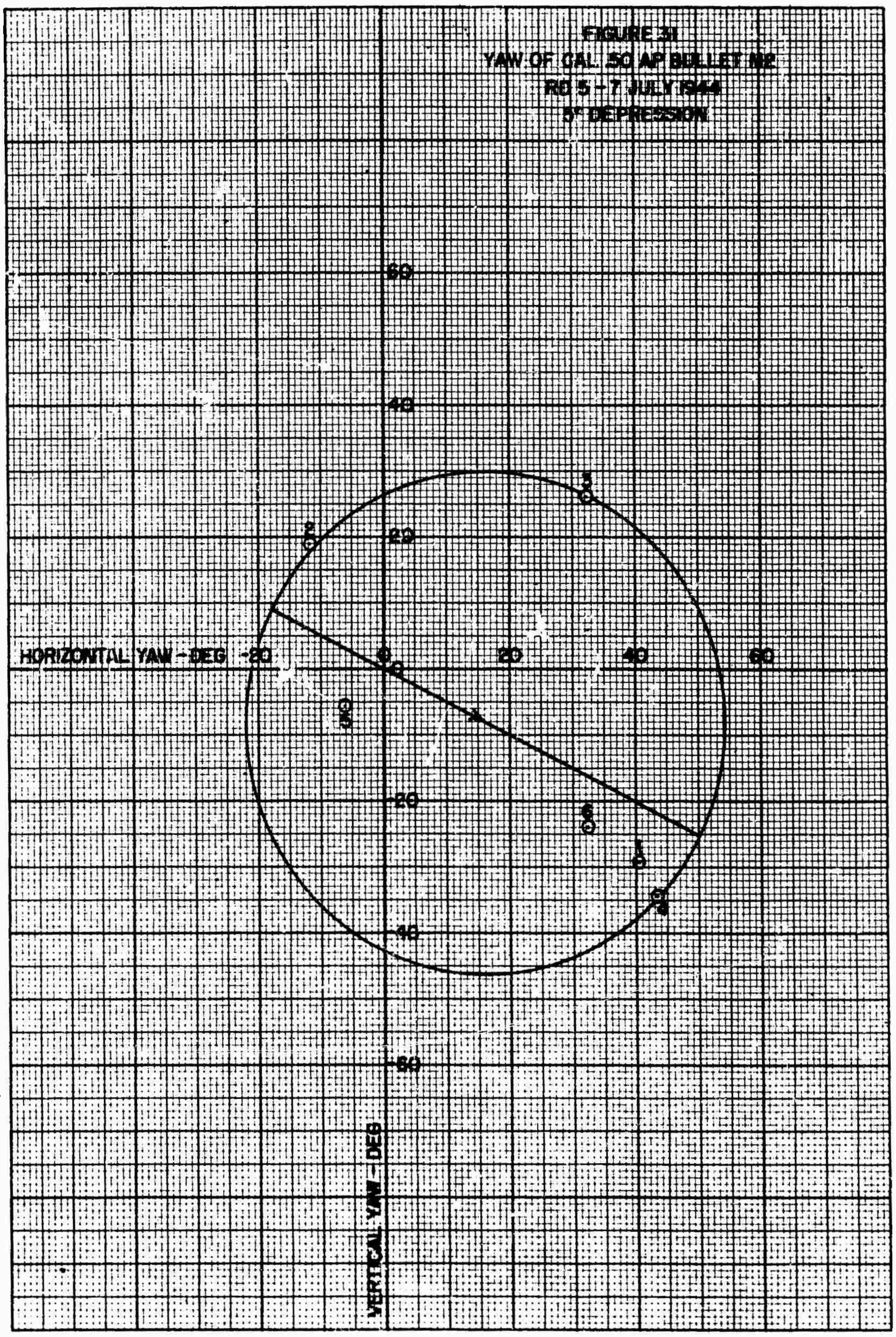


FIGURE 31
YAW OF CAL .50 AP BULLET M2
RD 5 - 7 JULY 1944
5° DEPRESSION

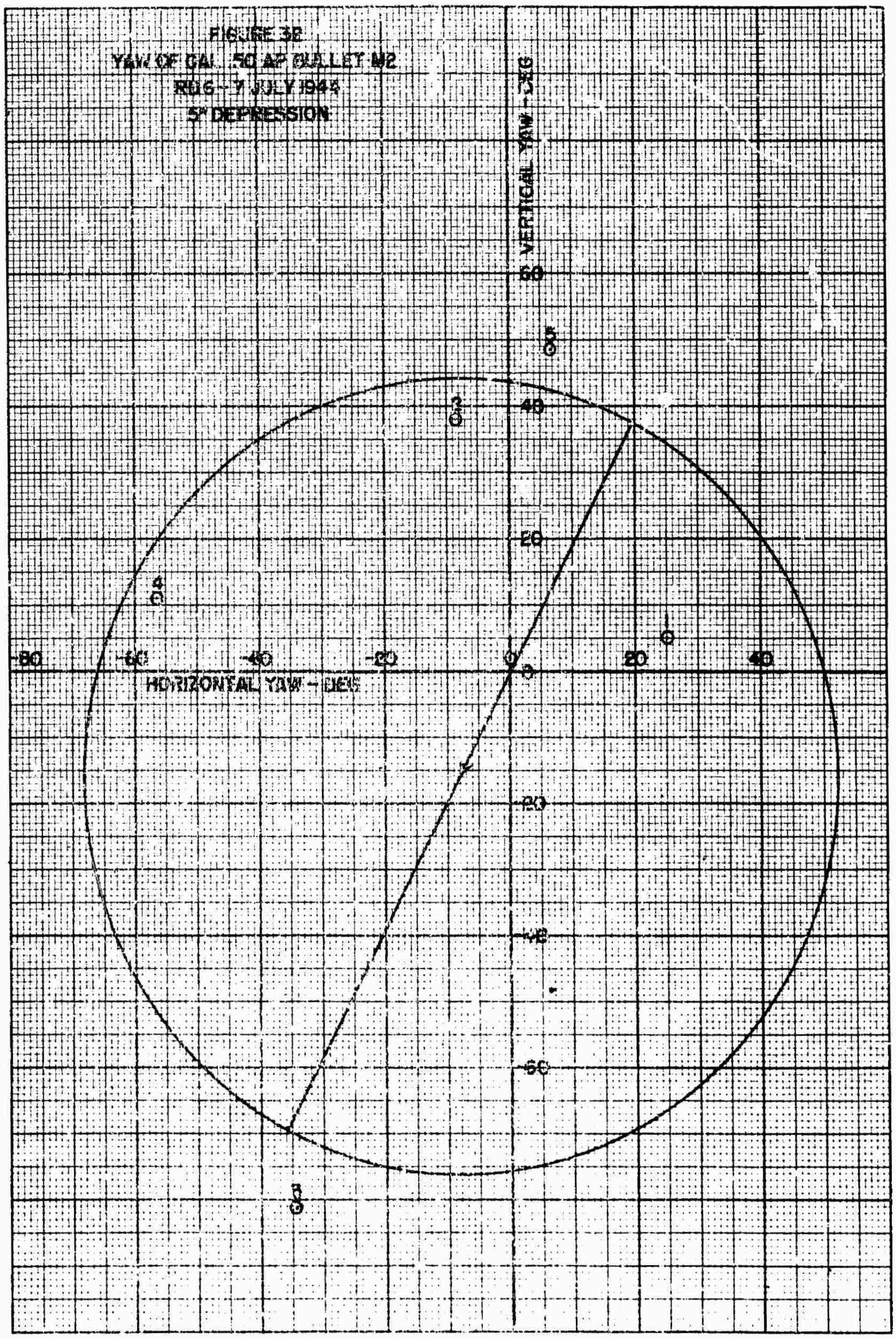


FIGURE 32
YAW OF CAL .50 AP BULLET M2
RD 6 - 7 JULY 1944
5° DEPRESSION
VERTICAL YAW - DEG
HORIZONTAL YAW - DEG
-80
-60
-40
-20
0
20
40
60
-20
-40
-60

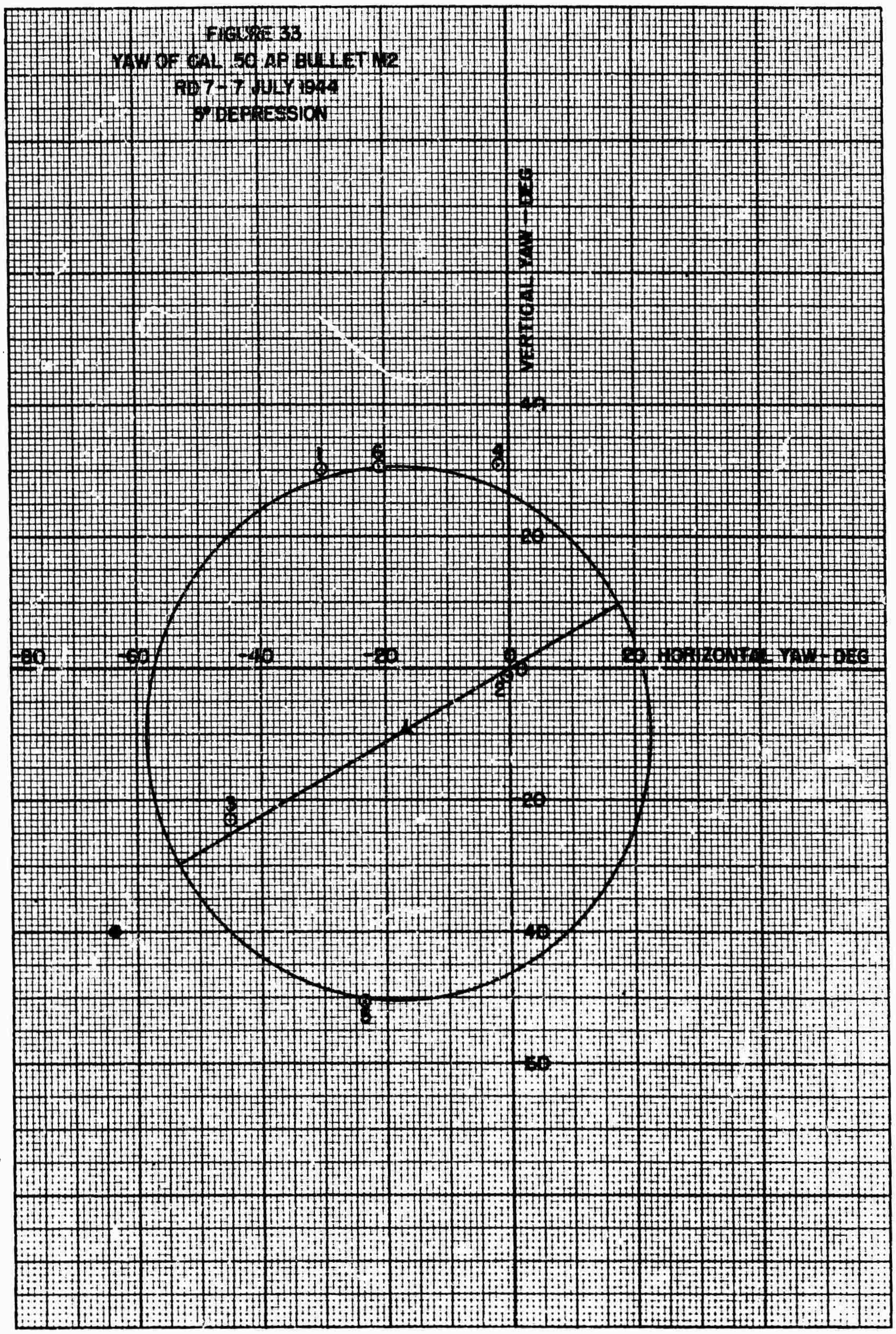


FIGURE 33
YAW OF CAL .50 AP BULLET M2
RD 7 – 7 JULY 1944
5° DEPRESSION

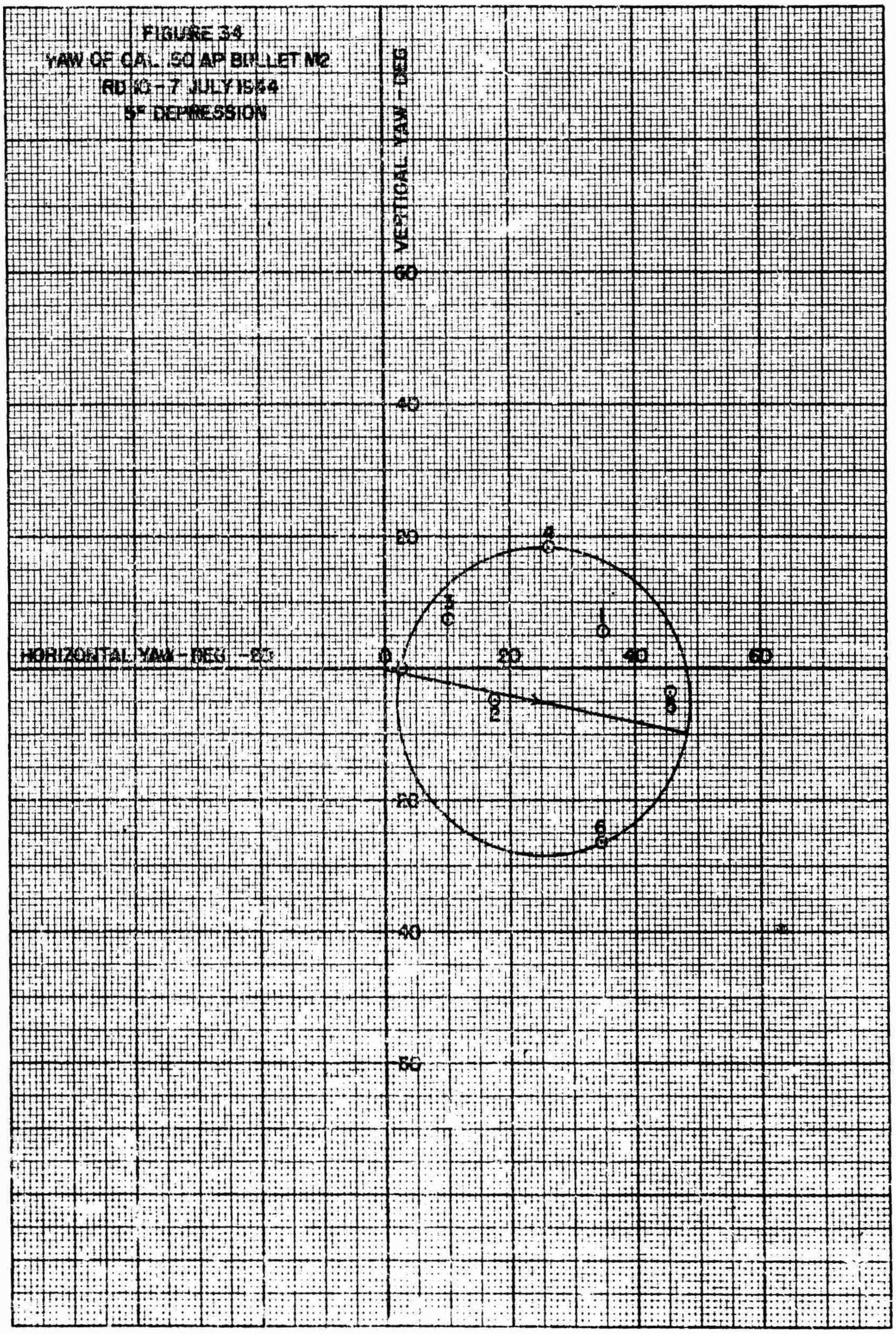


FIGURE 34
YAW OF CAL .50 AP BULLET M2
RD 10 – 7 JULY 1944
5° DEPRESSION

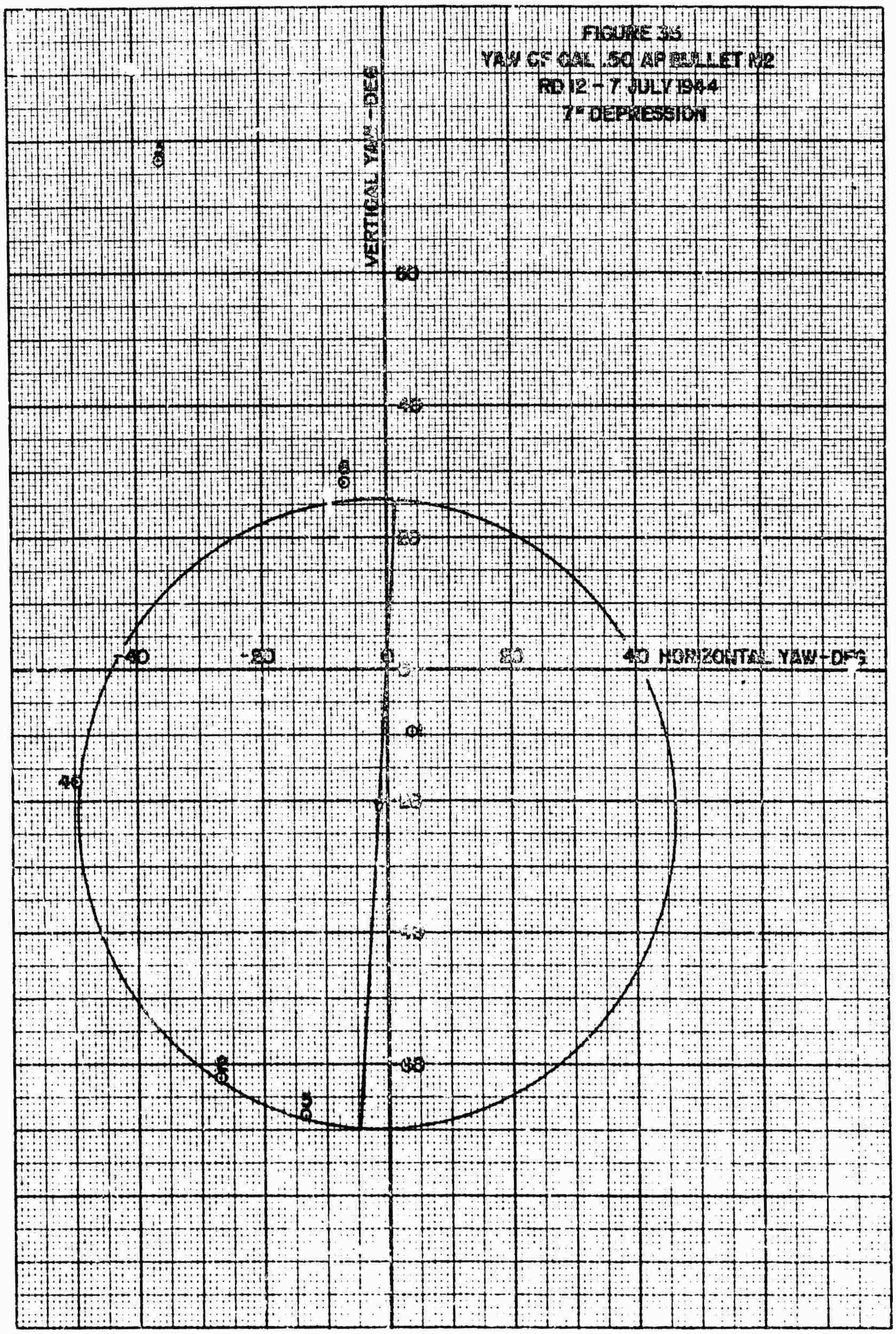


FIGURE 35
YAW OF CAL .50 AP BULLET M2
RD 12 - 7 JULY 1944
7° DEPRESSION

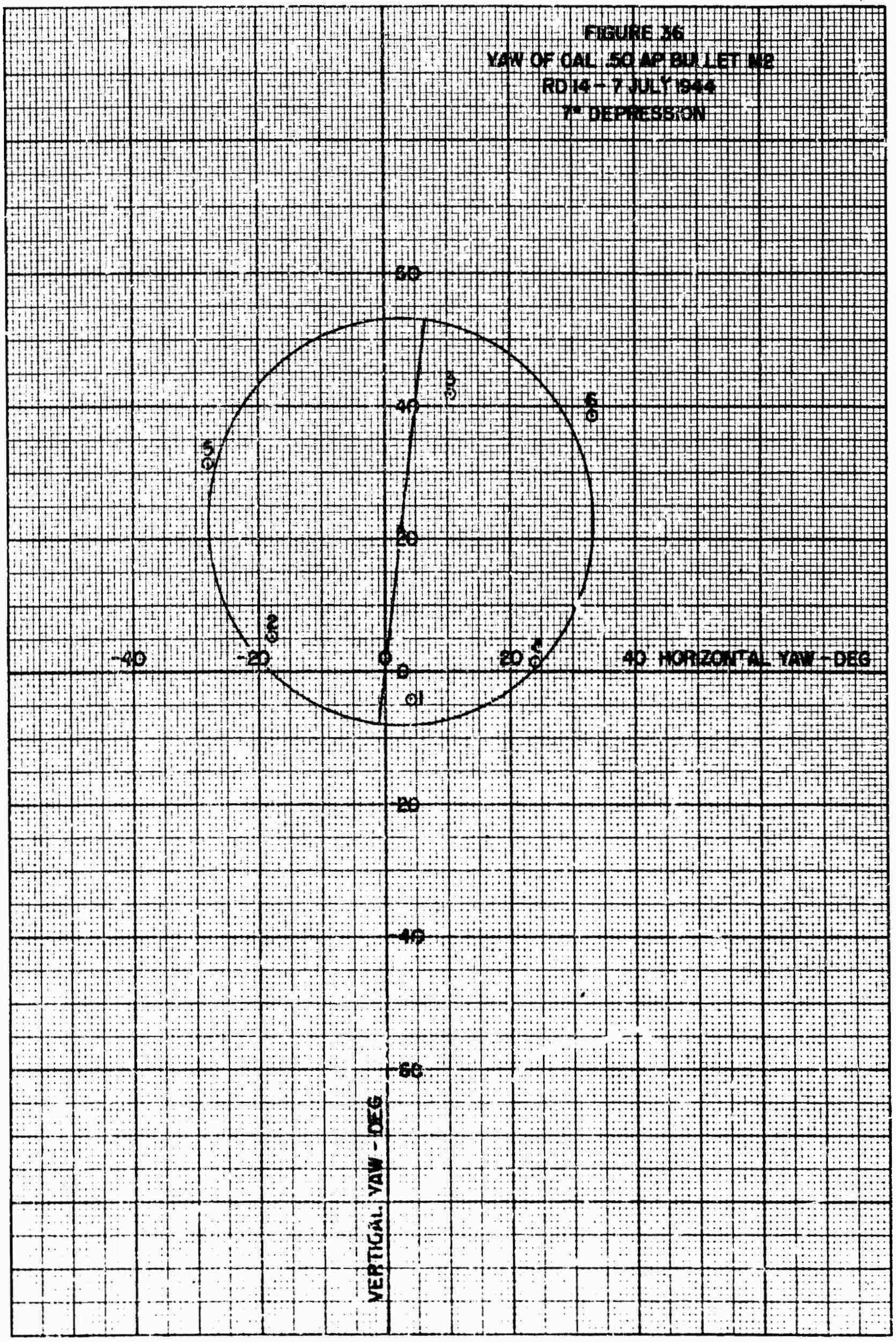


FIGURE 36
YAW OF CAL .50 AP BULLET M2
RD 14 - 7 JULY 1944
7° DEPRESSION

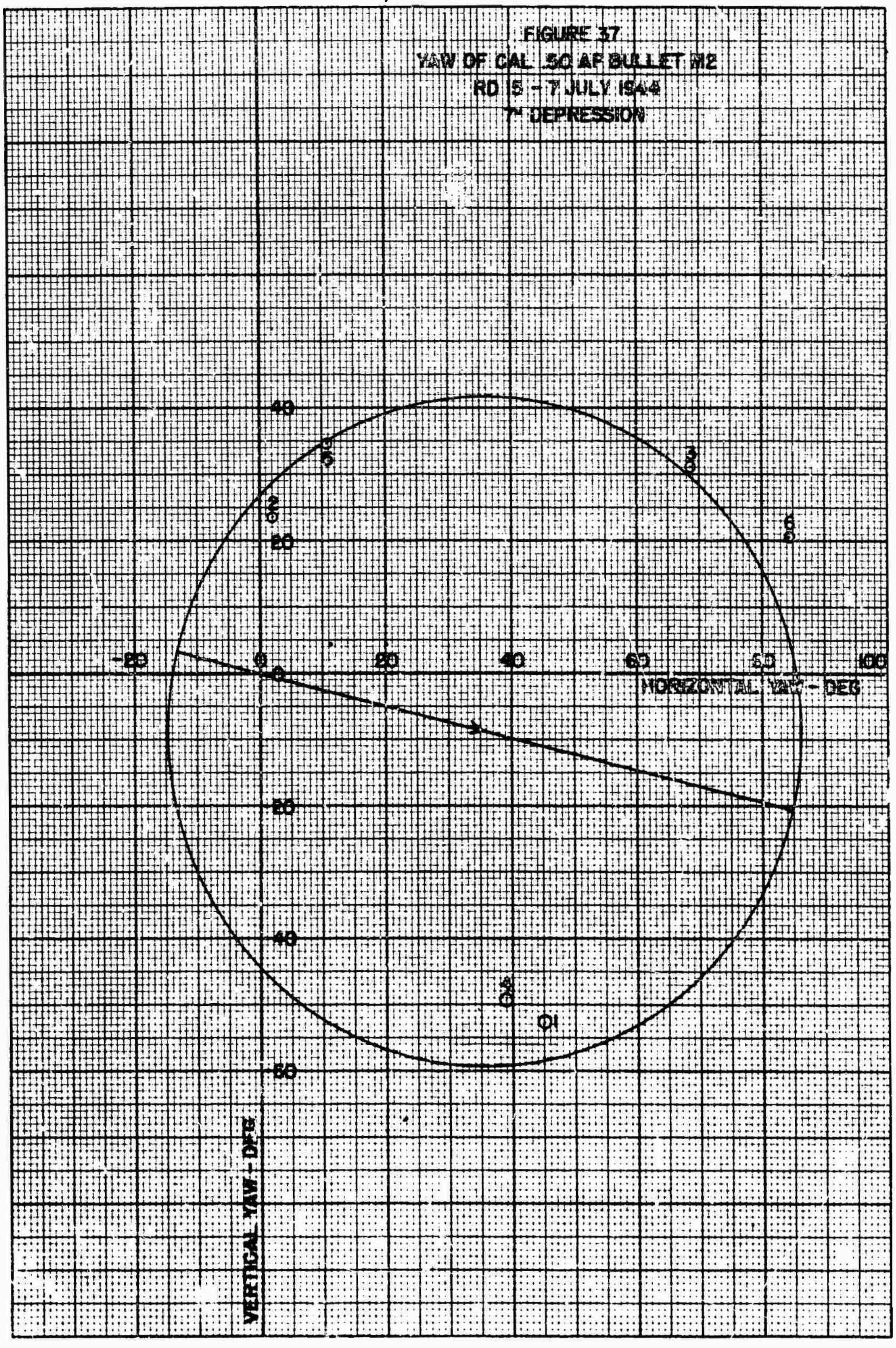


FIGURE 37
YAW OF CAL .50 AP BULLET M2
RD 5 - 7 JULY 1944
7° DEPRESSION

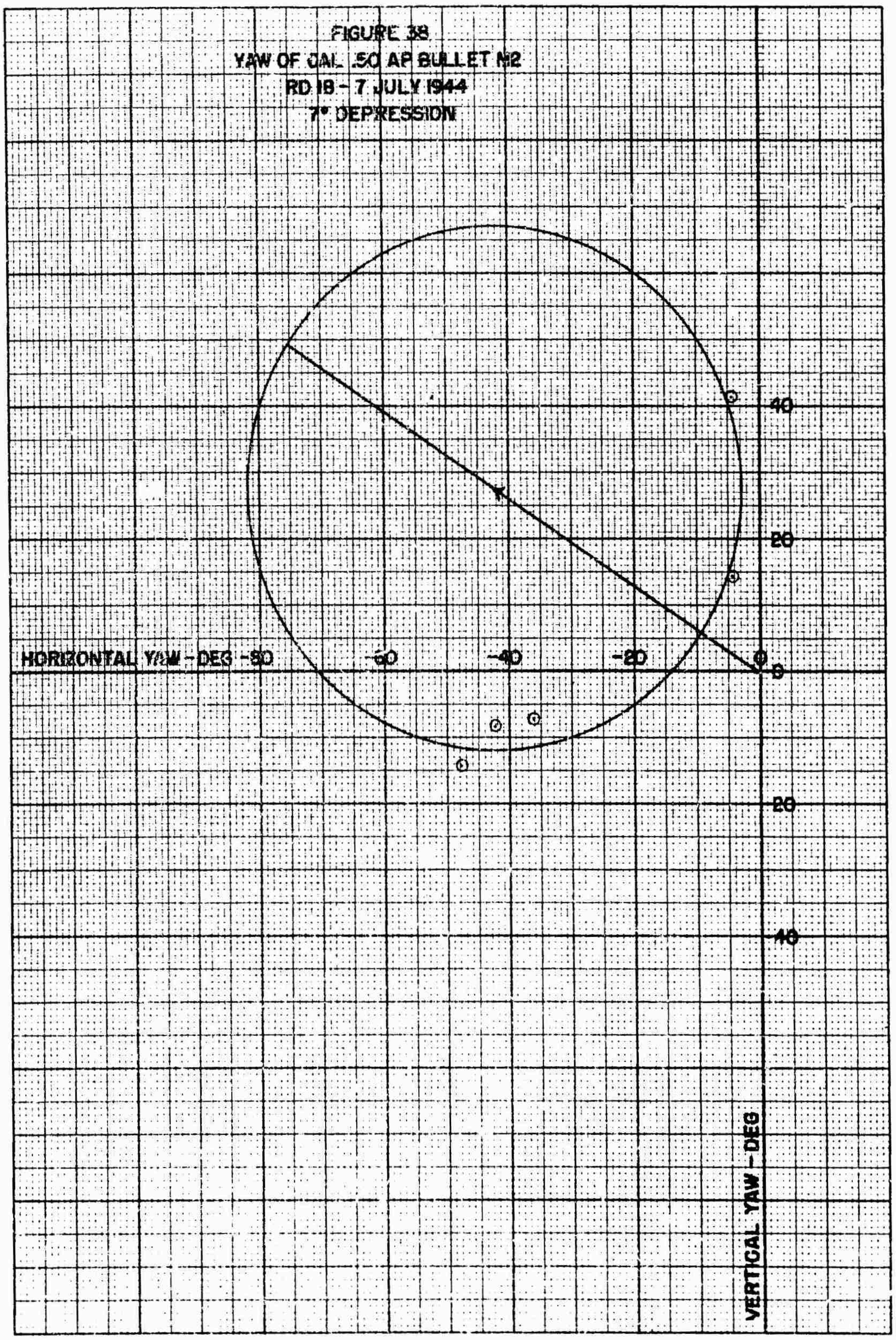


FIGURE 38
YAW OF CAL .50 AP BULLET M2
RD 18 - 7 JULY 1944
7° DEPRESSION
HORIZONTAL YAW - DEG -80
-60
-40
-20
0
40
20
20
-40
VERTICAL YAW - DEG

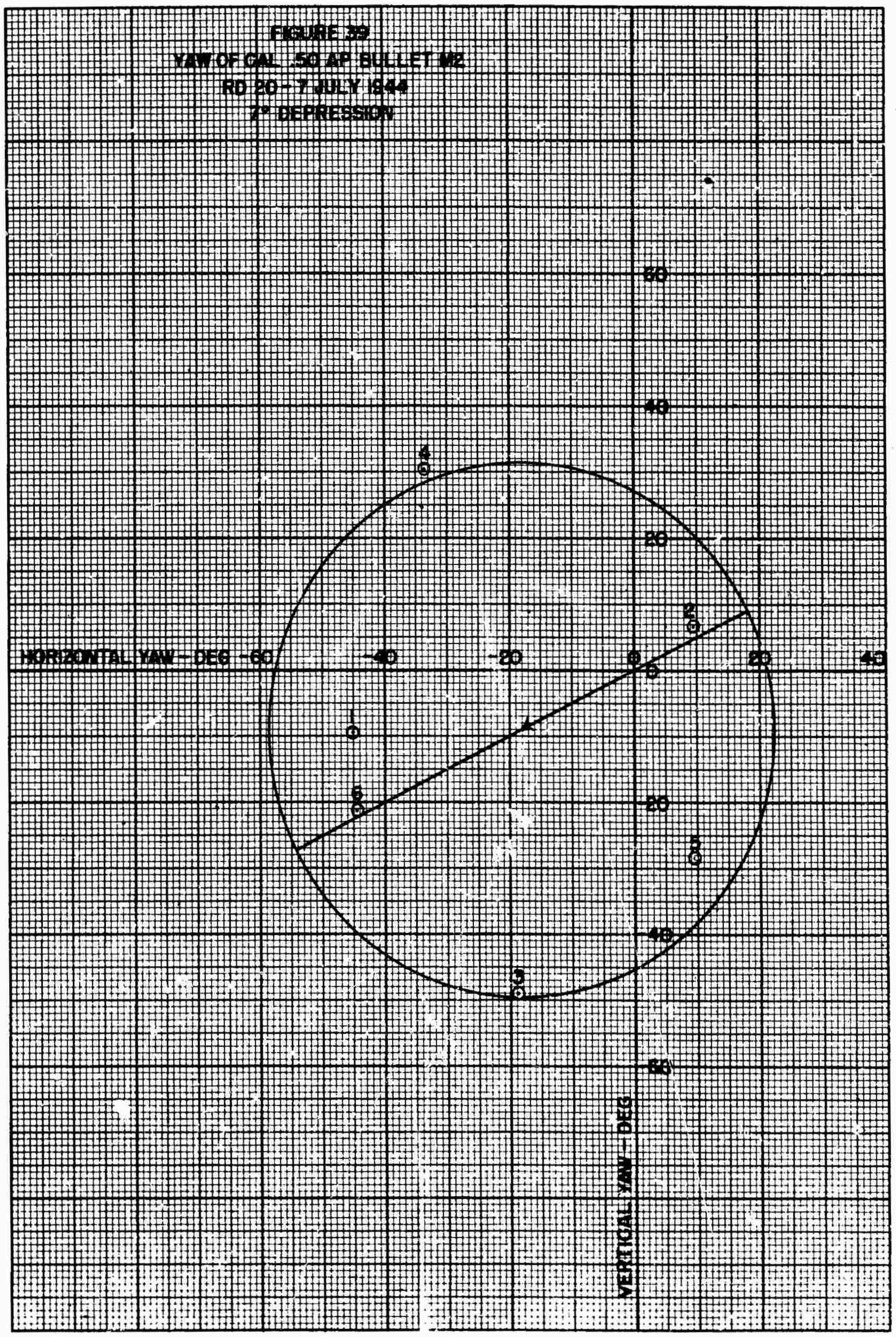


FIGURE 39
YAW OF CAL .50 AP BULLET M2
RD 20 - 7 JULY 1944
2° DEPRESSION
HORIZONTAL YAW - DEG
VERTICAL YAW - DEG
-60
-40
-20
0
20
40
60
1
2
3
4
5
6

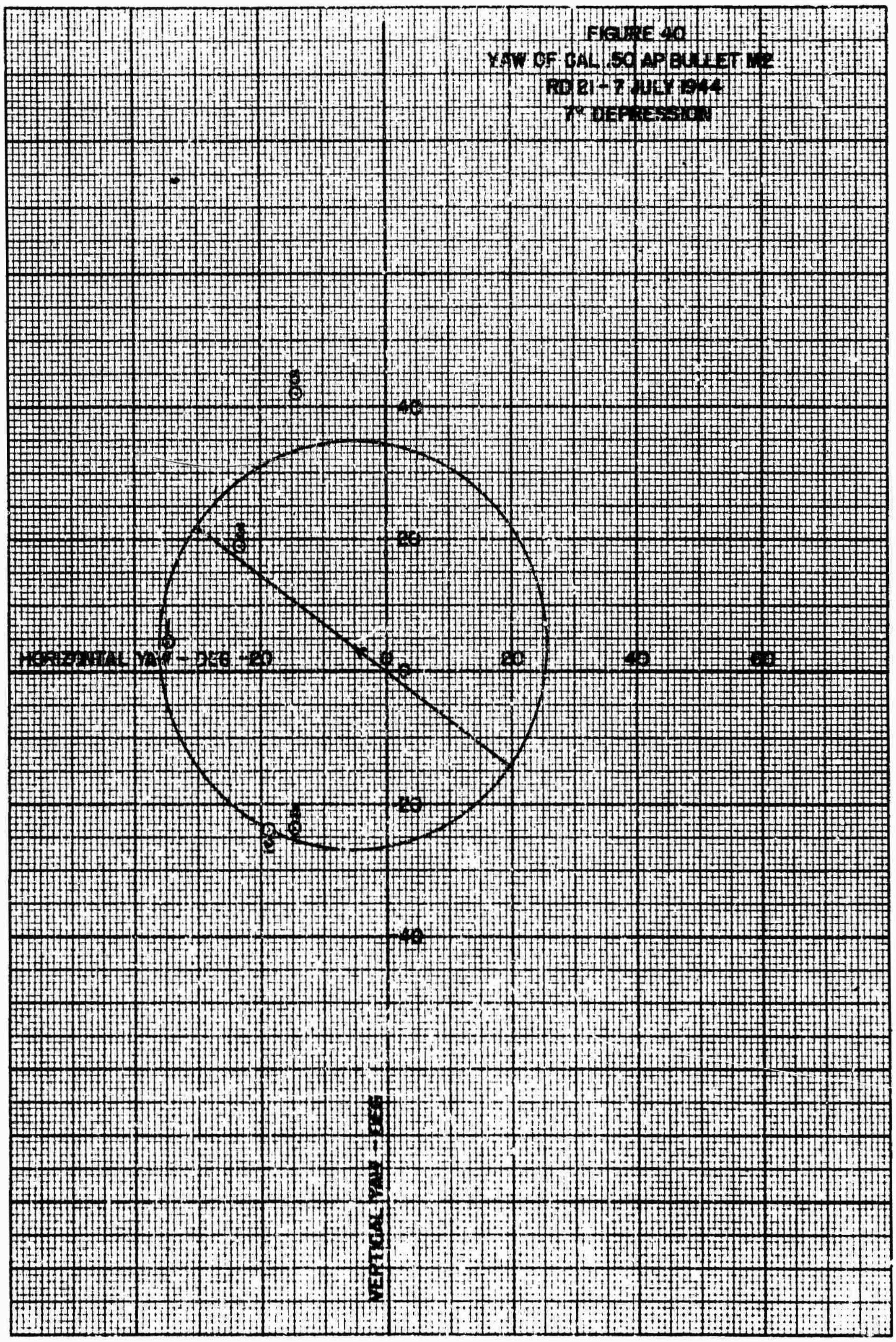


FIGURE 40
YAW OF CAL .50 AP BULLET M2
RD 21 - 7 JULY 1944
7° DEPRESSION
HORIZONTAL YAW - DEG
-20
0
20
40
60
40
20
-20
-40
VERTICAL YAW - DEG

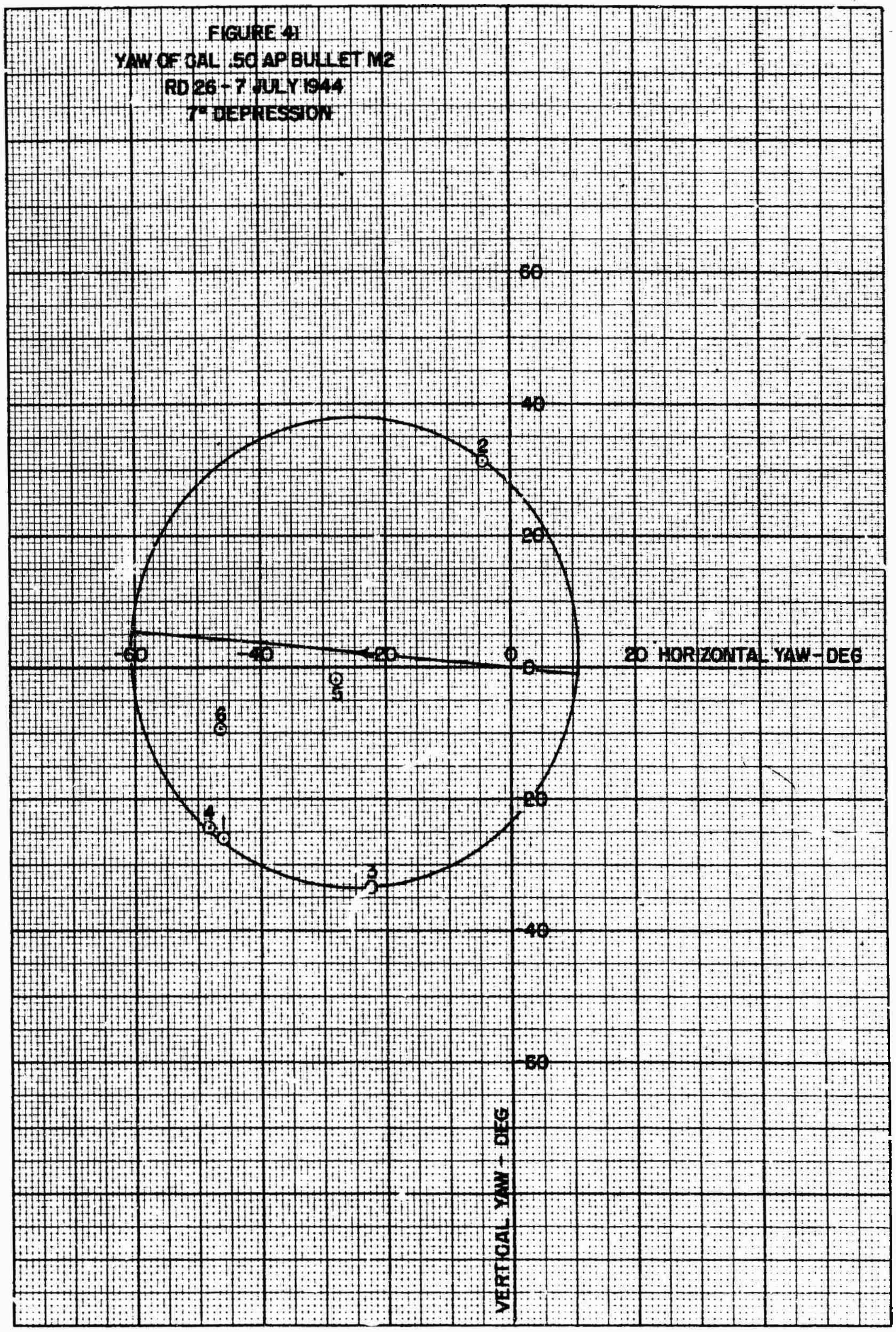


FIGURE 41
YAW OF CAL .50 AP BULLET M2
RD 26 - 7 JULY 1944
7° DEPRESSION

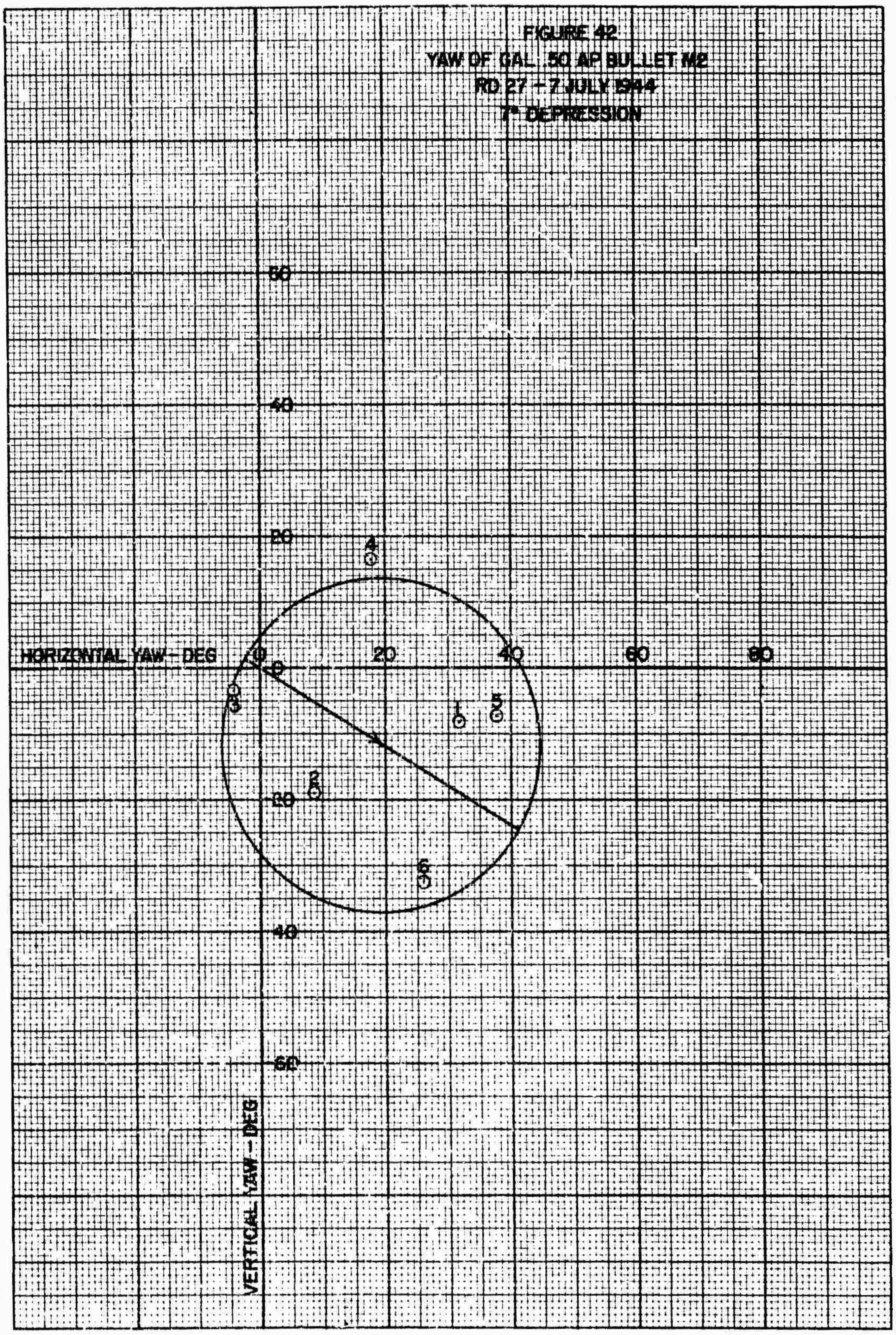


FIGURE 42
YAW OF CAL .50 AP BULLET M2
RD 27 - 7 JULY 1944
7° DEPRESSION
HORIZONTAL YAW - DEG
VERTICAL YAW - DEG
0
20
40
60
80
4
1
5
3
2
6

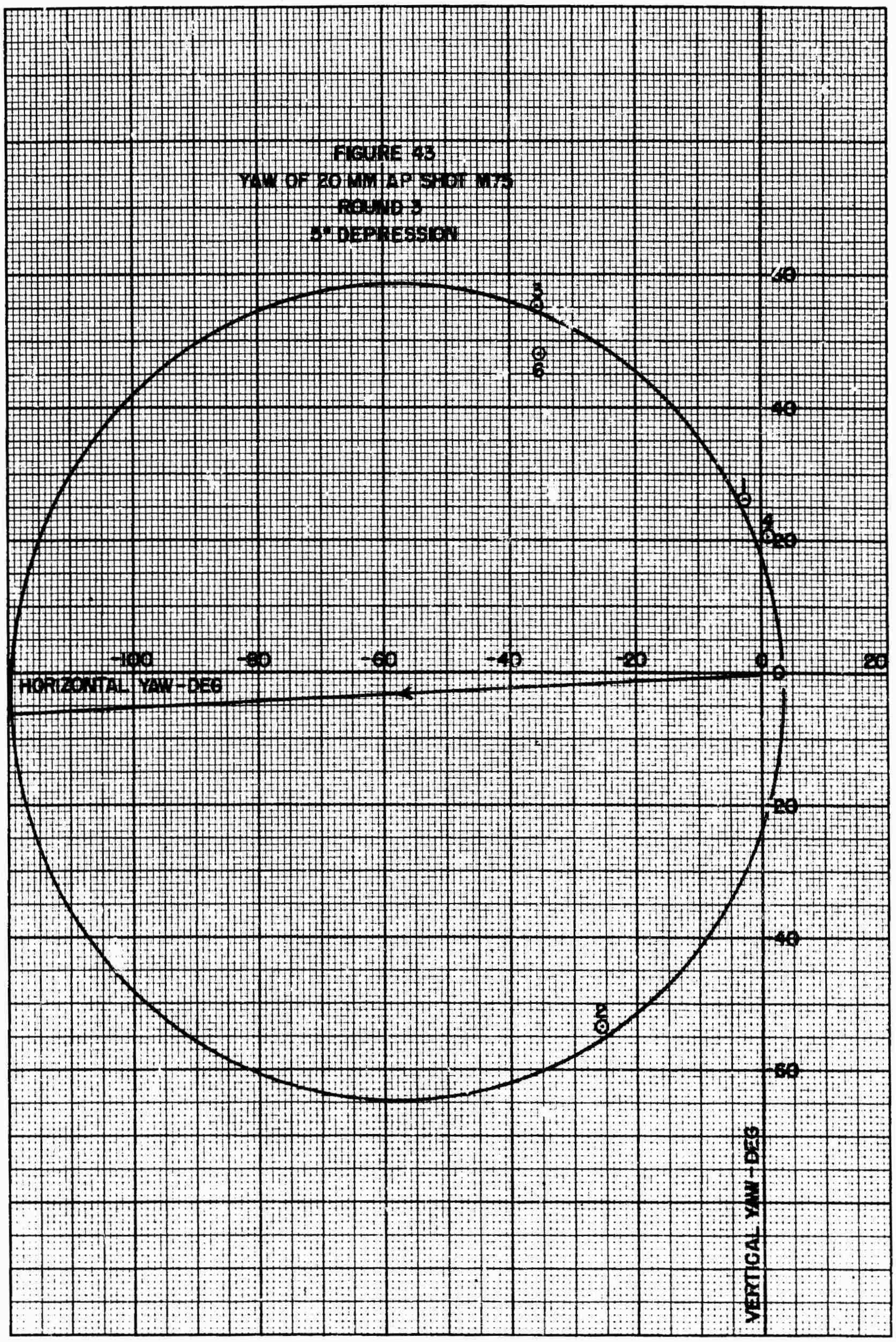


FIGURE 43
YAW OF 20 MM AP SHOT M75
ROUND 3
5° DEPRESSION
HORIZONTAL YAW - DEG
VERTICAL YAW - DEG
-100
-80
-60
-40
-20
0
20
40
20
0
-20
-40
-60

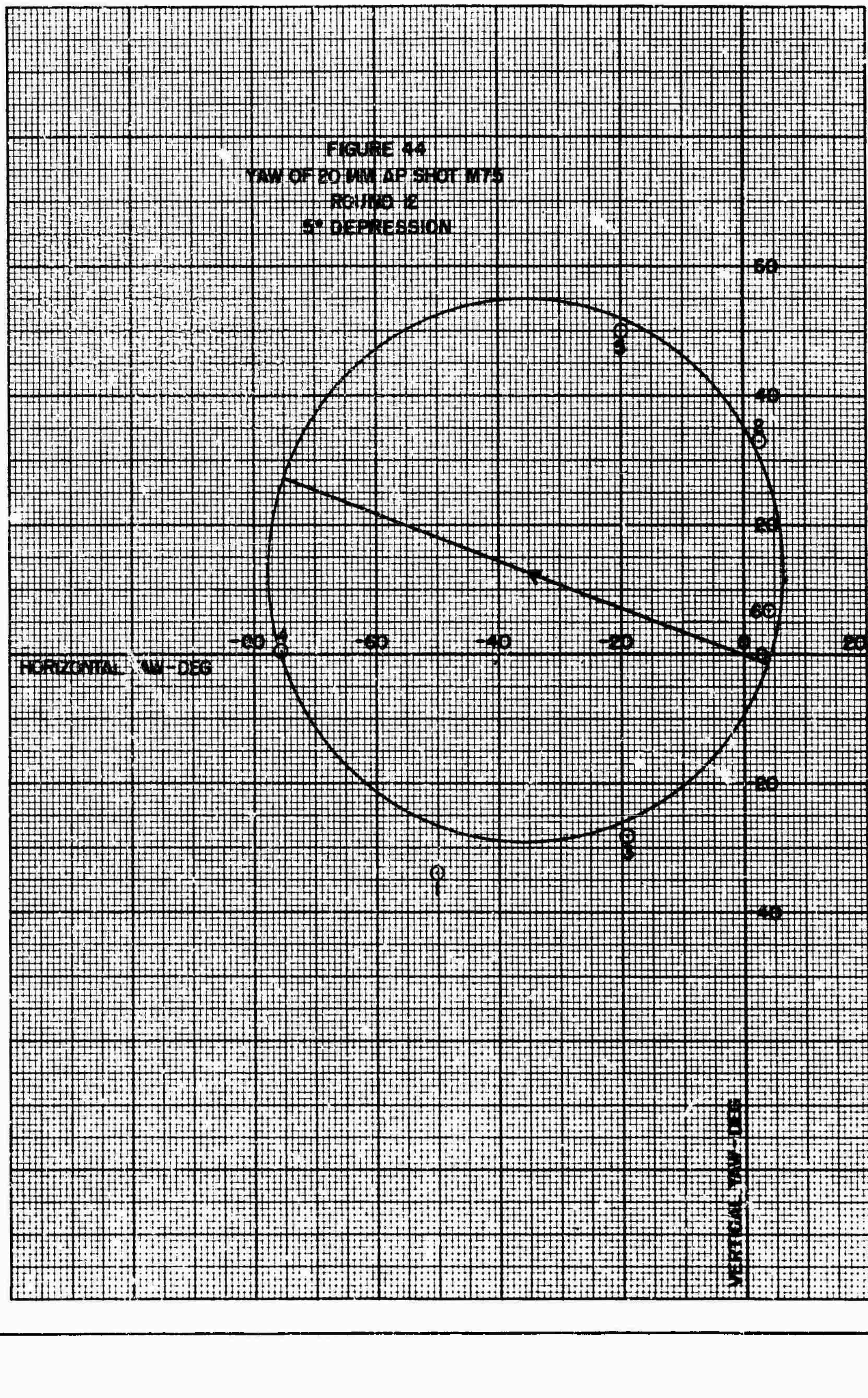


FIGURE 44
YAW OF 20 MM AP SHOT M75
ROUND 12
5° DEPRESSION
HORIZONTAL YAW - DEG
VERTICAL YAW - DEG
-80
-60
-40
-20
0
20
60
40
20
20
40

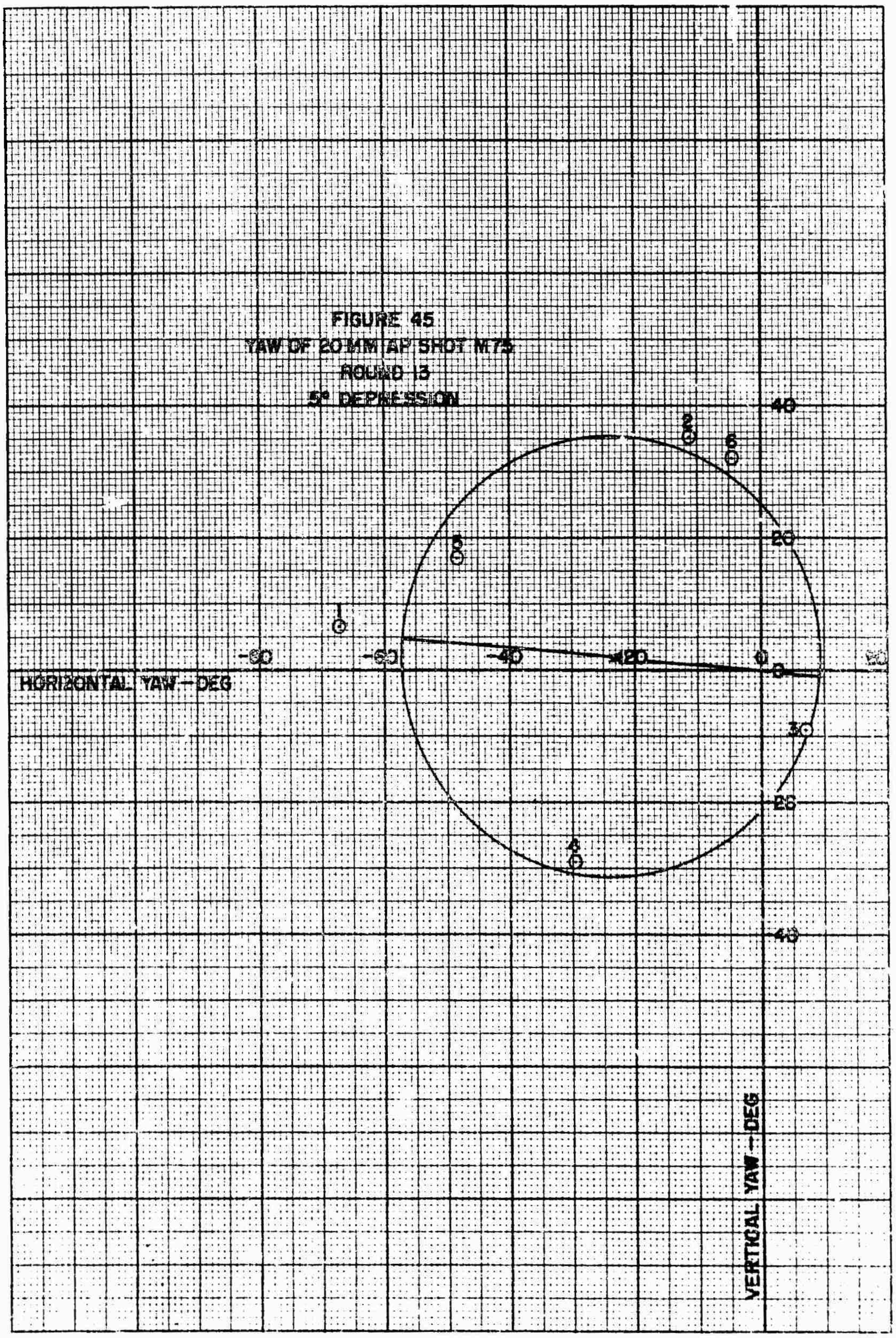


FIGURE 45
YAW OF 20 MM AP SHOT M75
ROUND 13
5° DEPRESSION
HORIZONTAL YAW—DEG
VERTICAL YAW—DEG
-80
-60
-40
-20
0
20
40
20
40
20
40
1
2
3
4
5
6
0

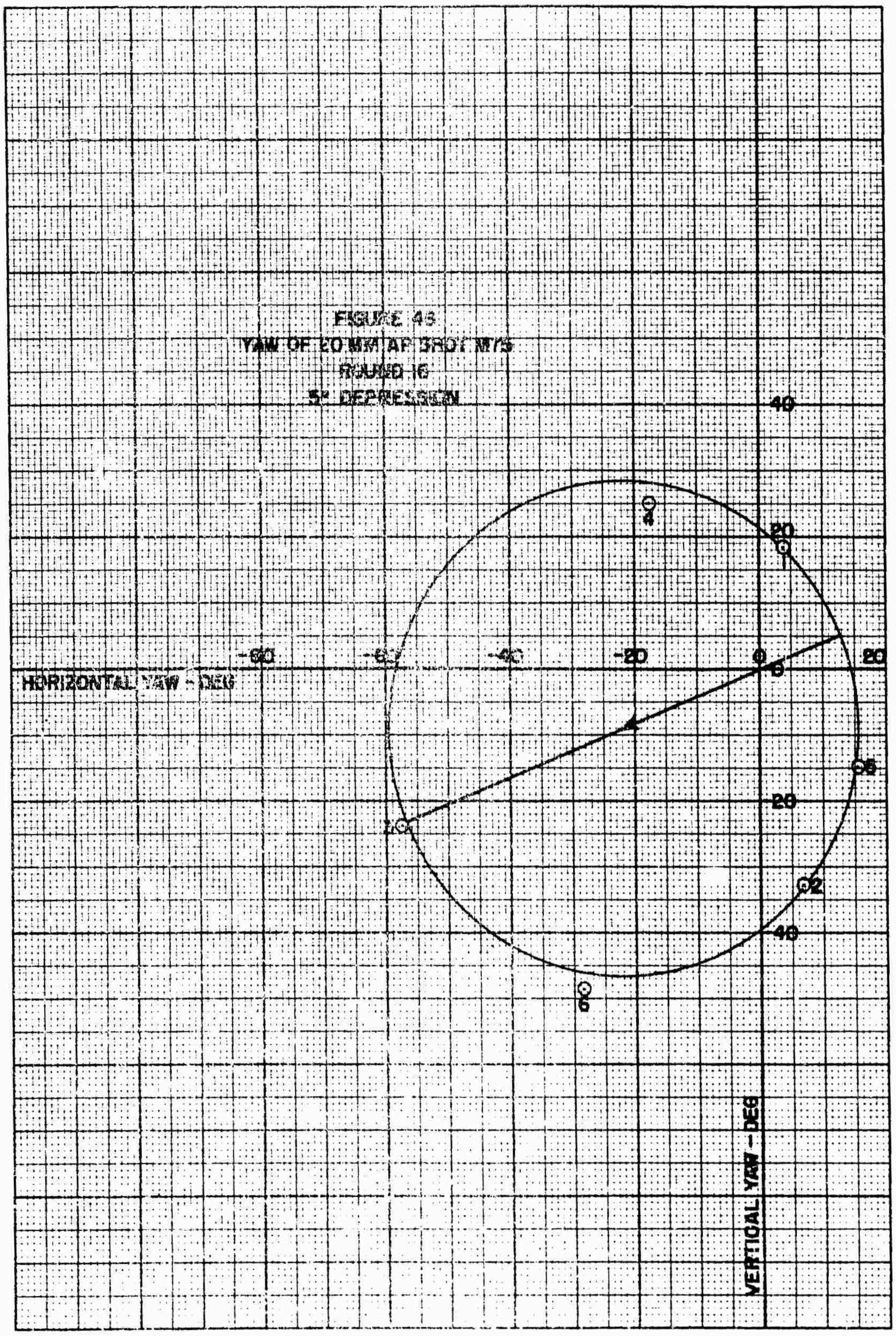


FIGURE 43
YAW OF 20 MM AP SHOT M75
ROUND 16
5° DEPRESSION
HORIZONTAL YAW - DEG
VERTICAL YAW - DEG
-60
-40
-20
0
20
40
-20
-40
1
2
4
5
6
7
8

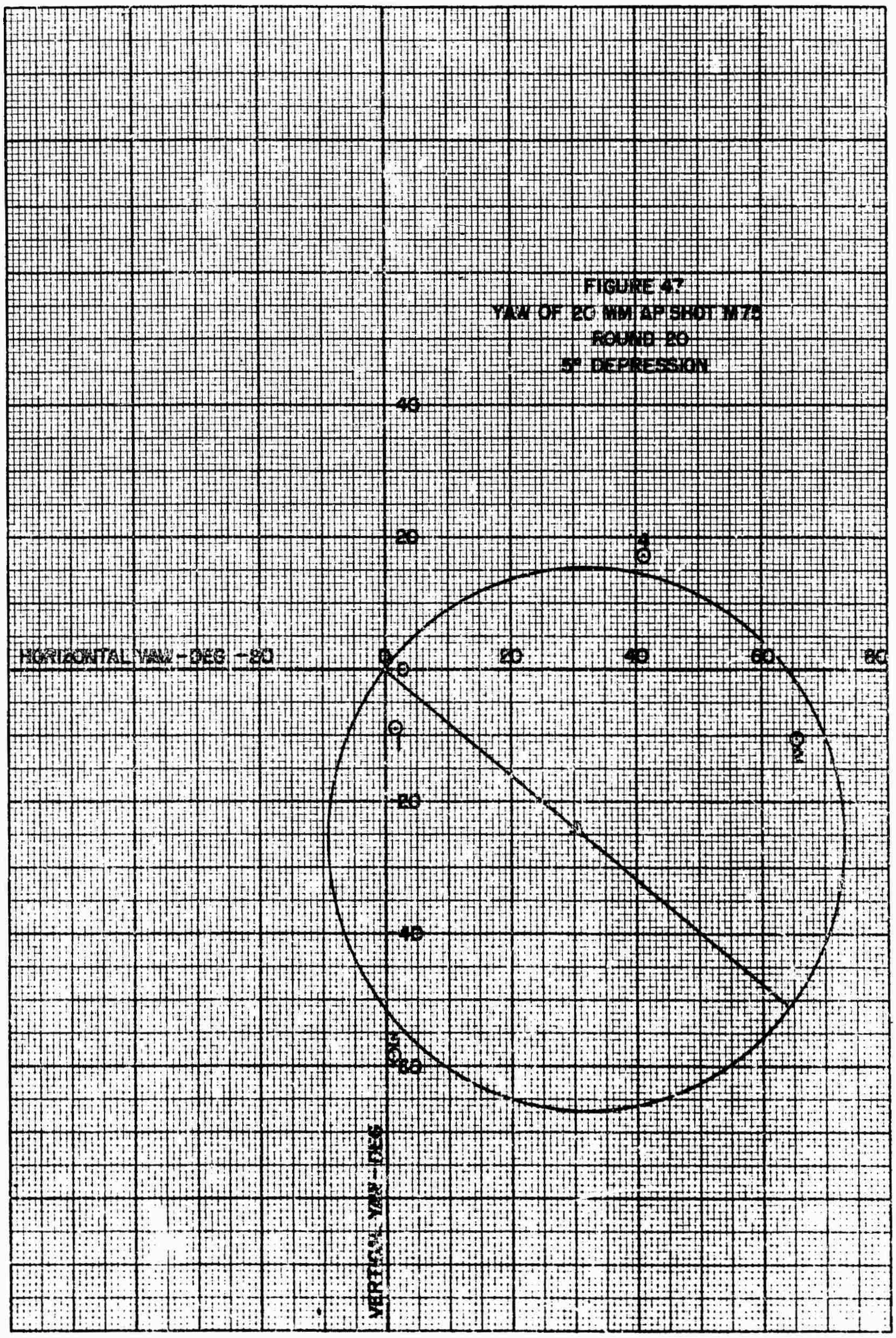


FIGURE 47
YAW OF 20 MM AP SHOT M75
ROUND 20
5° DEPRESSION
HORIZONTAL YAW - DEG
VERTICAL YAW - DEG
-20
0
20
40
60
80
-20
-40
-60
20
40

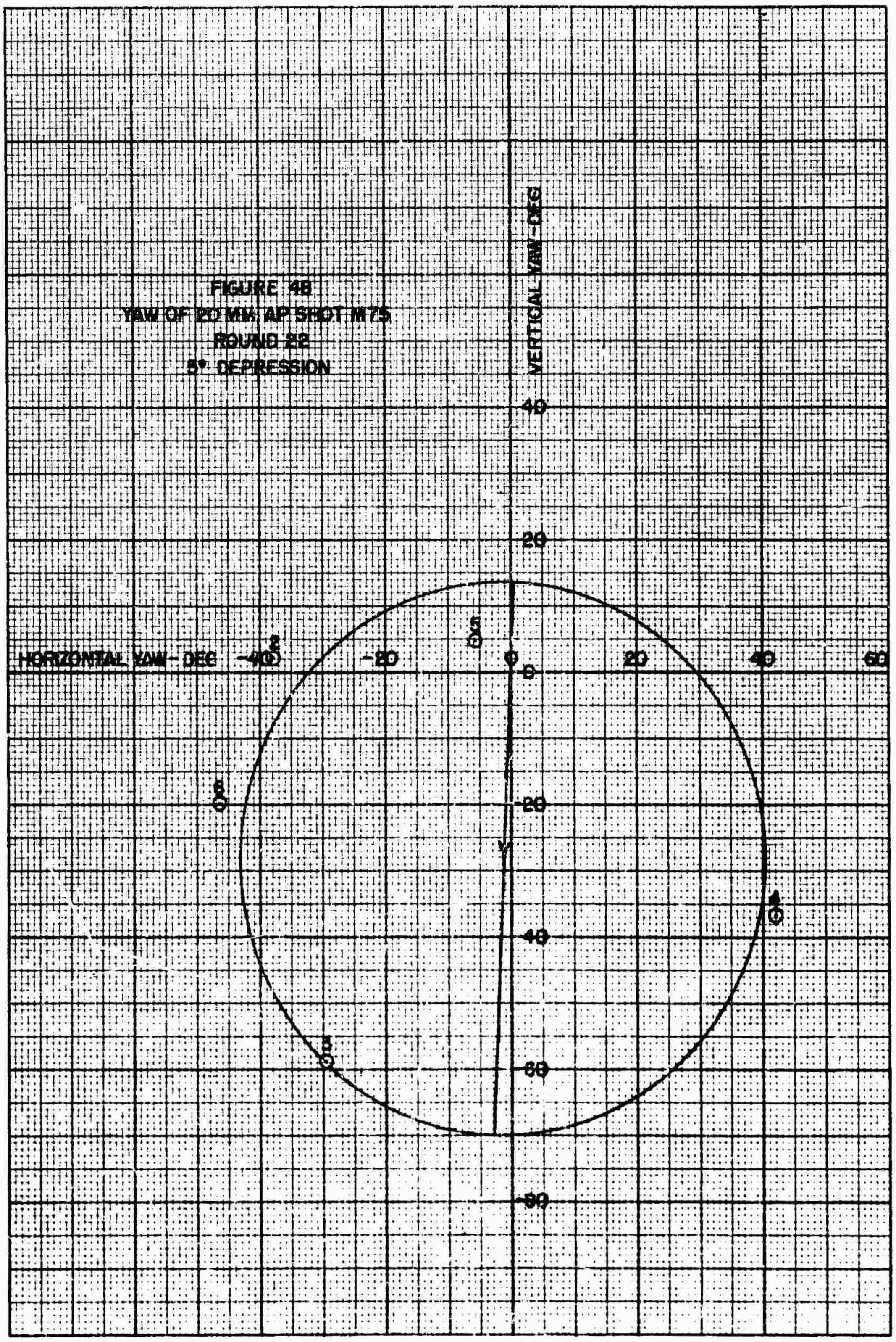


FIGURE 48
YAW OF 20 MM AP SHOT M75
ROUND 22
5° DEPRESSION
VERTICAL YAW-DEG
HORIZONTAL YAW-DEG
-40
-20
0
20
40
60
-20
-40
-60
-80

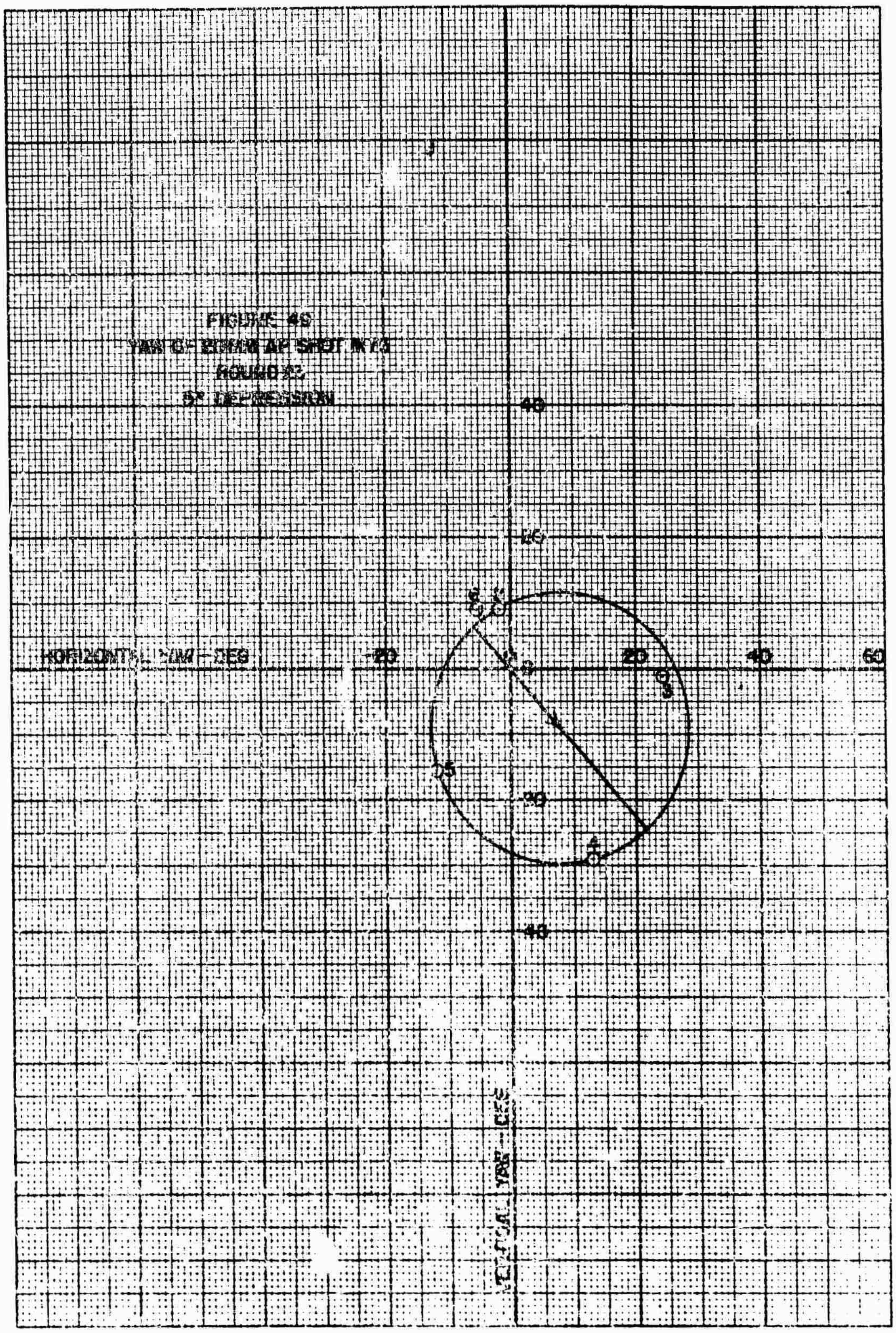


FIGURE 49
40
20
-20
20
40
60
-20
-40

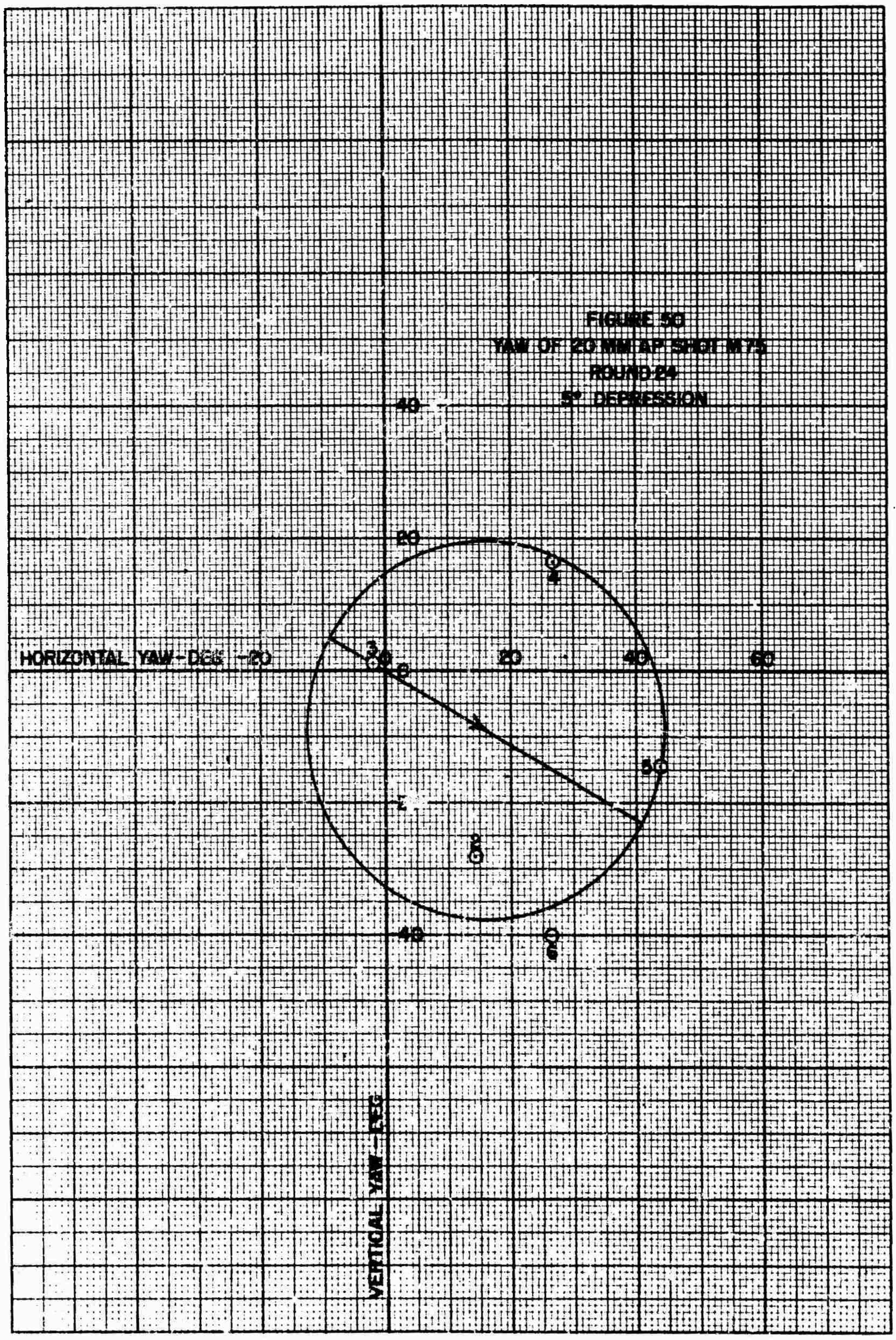


FIGURE 50
YAW OF 20 MM AP SHOT M75
ROUND 24
5° DEPRESSION
HORIZONTAL YAW-DEG -20
20
40
60
40
20
40
VERTICAL YAW-DEG

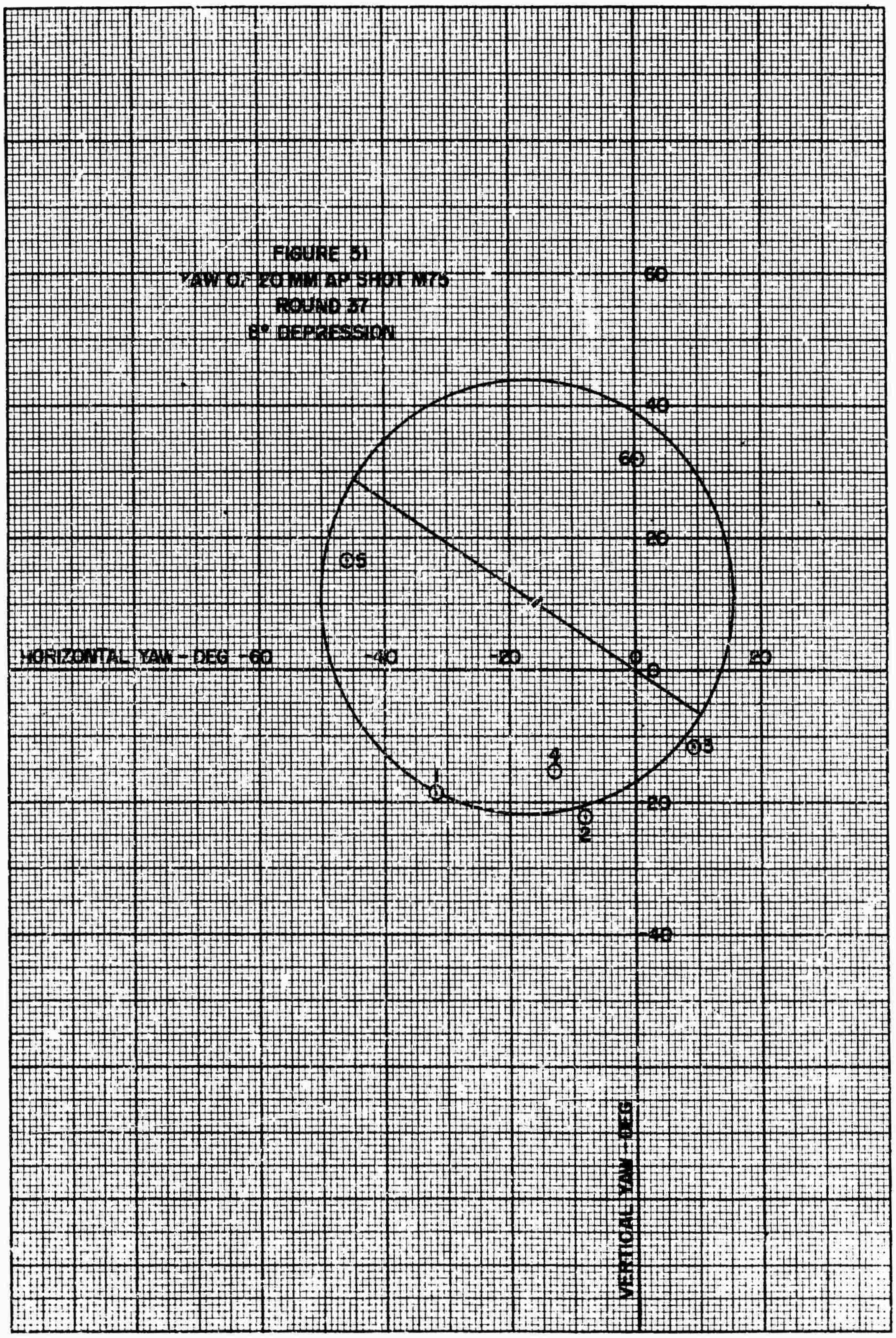


FIGURE 51
YAW OF 20 MM AP SHOT M75
ROUND 37
8° DEPRESSION

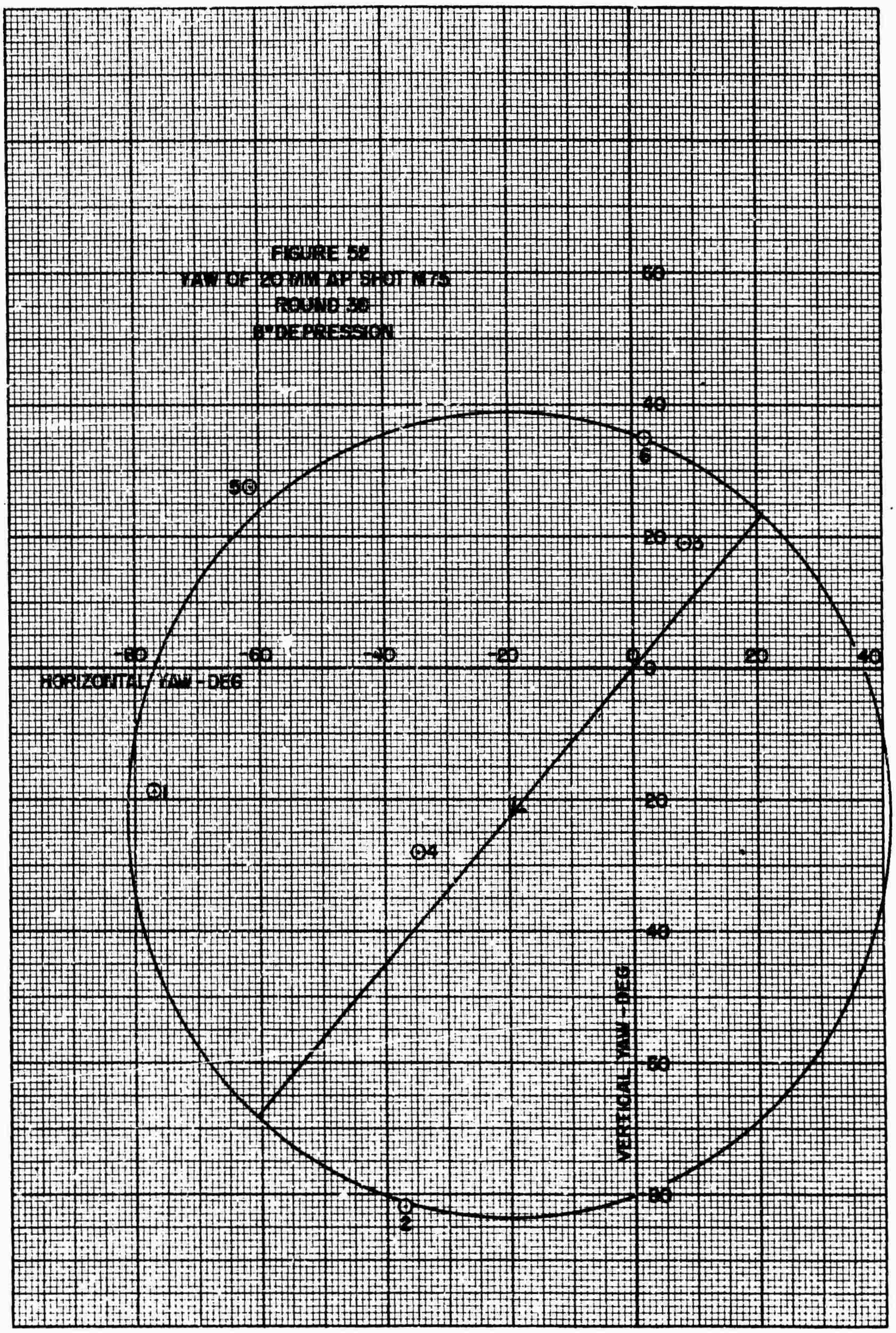


FIGURE 52
YAW OF 20 MM AP SHOT M75
ROUND 30
8° DEPRESSION

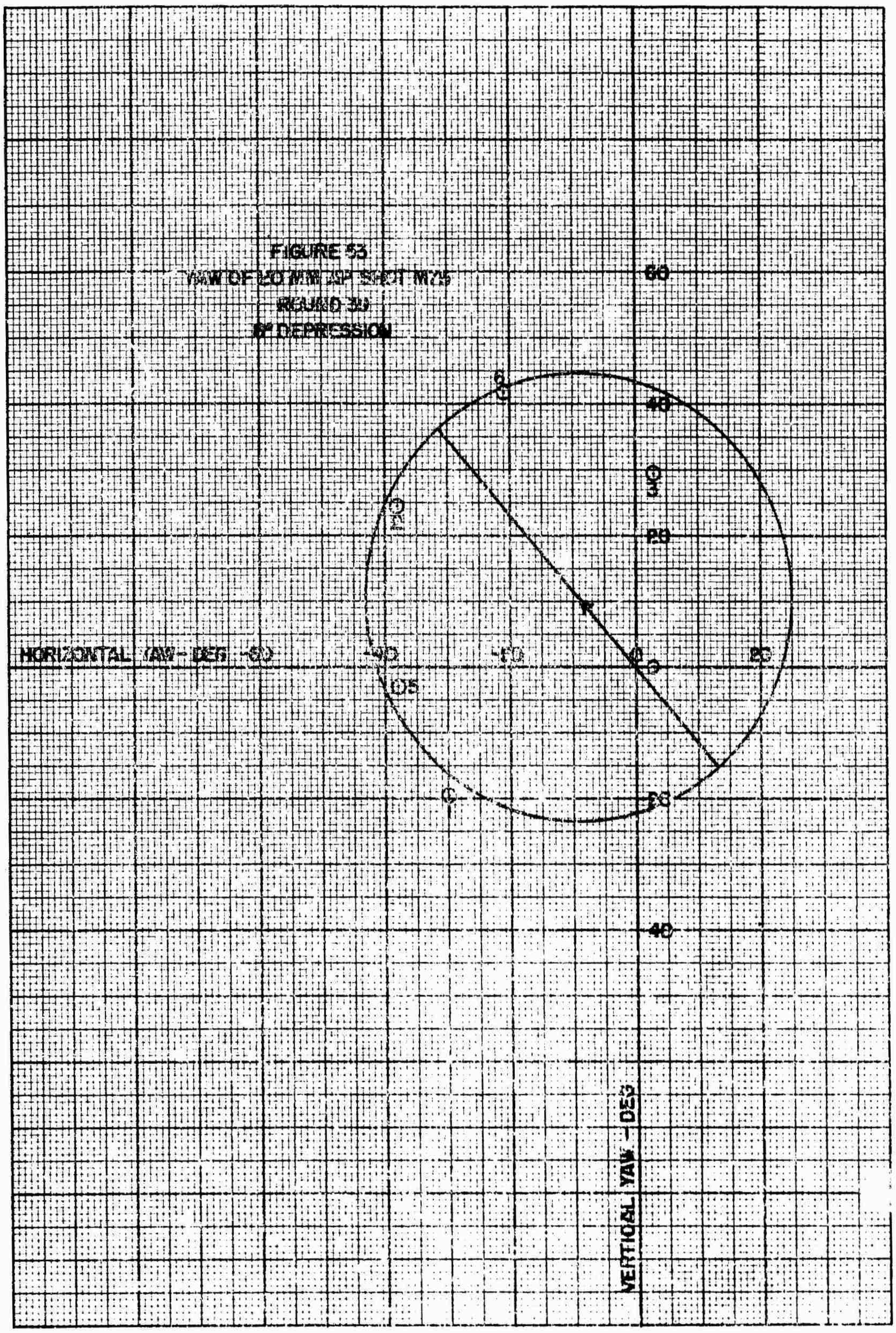


FIGURE 53
YAW OF 20 MM AP SHOT M75
ROUND 30
3° DEPRESSION

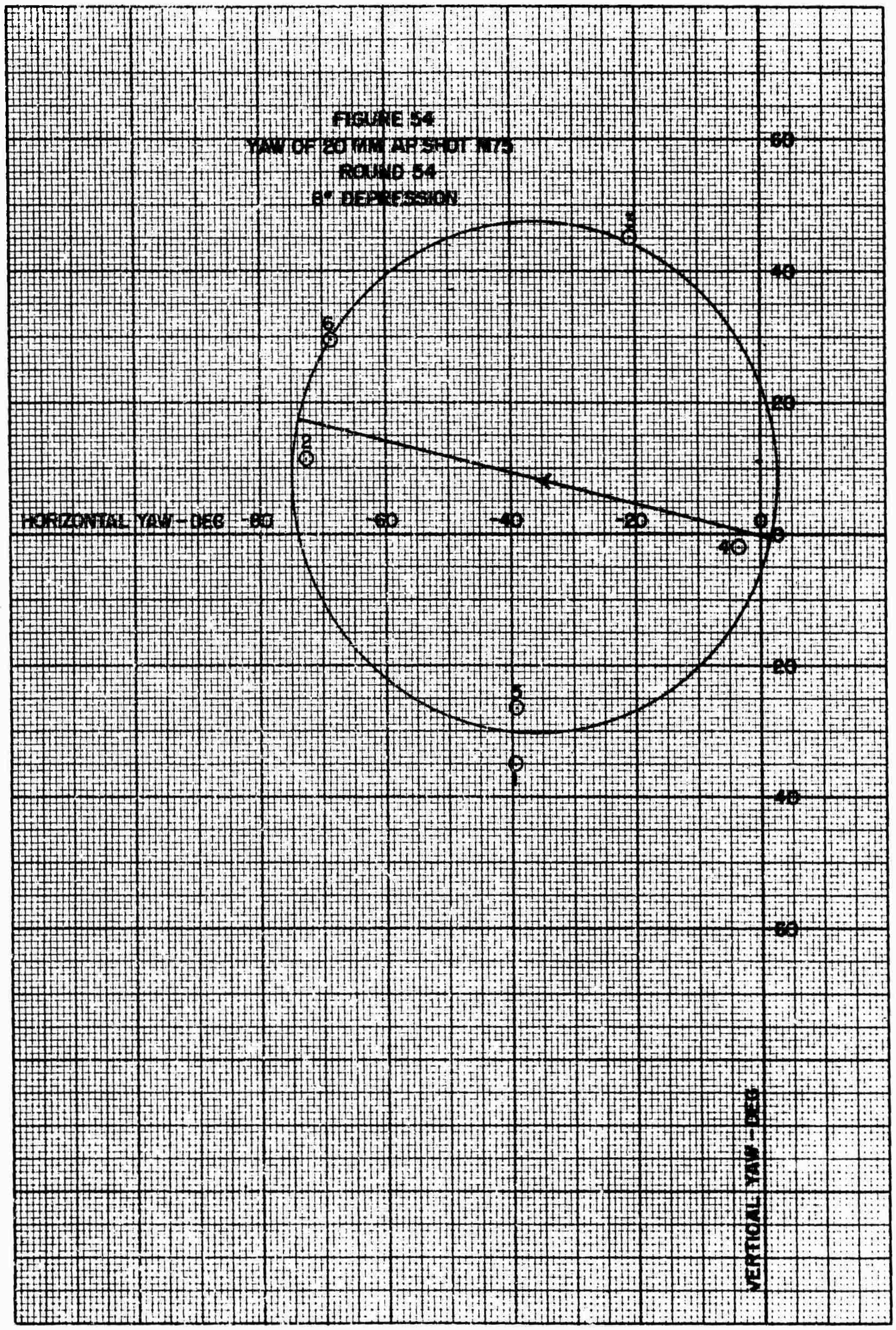
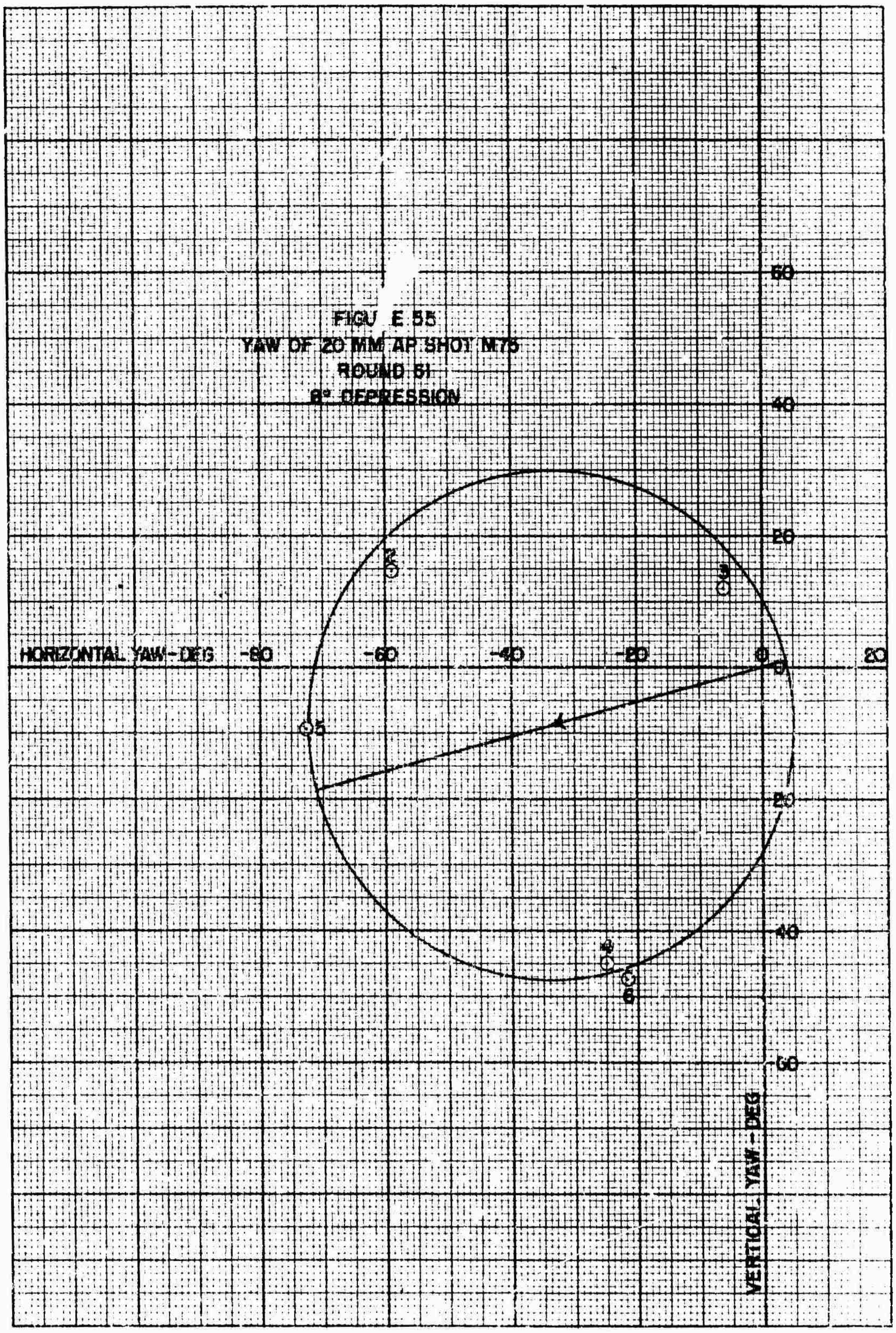


FIGURE 54
YAW OF 20 MM AP SHOT M75
ROUND 54
8° DEPRESSION
HORIZONTAL YAW - DEG
-80
-60
-40
-20
0
60
40
20
20
40
60
VERTICAL YAW - DEG



FIGU E 55
YAW OF 20 MM AP SHOT M75
ROUND 51
8° DEPRESSION

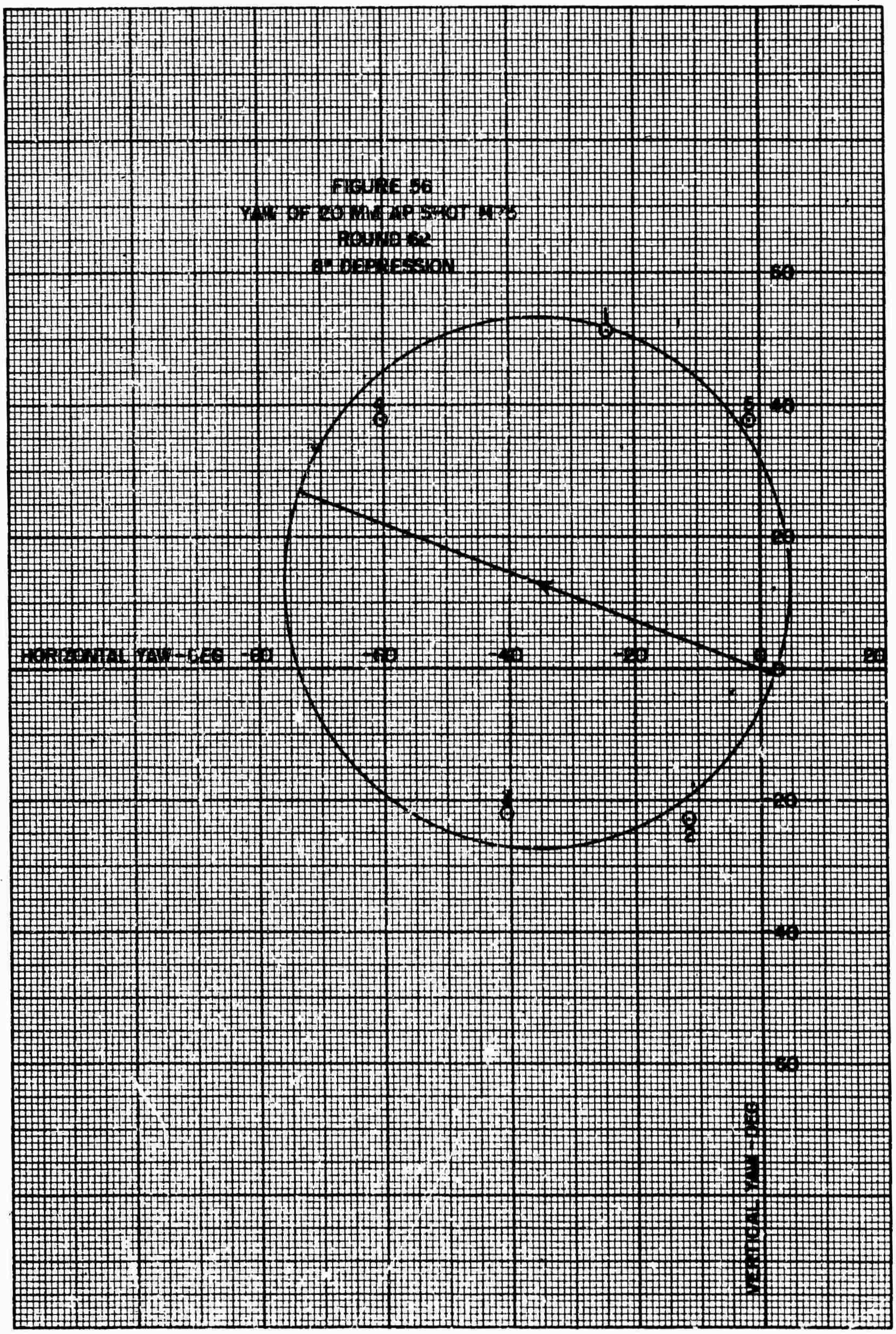


FIGURE 56
YAW OF 20 MM AP SHOT M75
ROUND 62
8° DEPRESSION

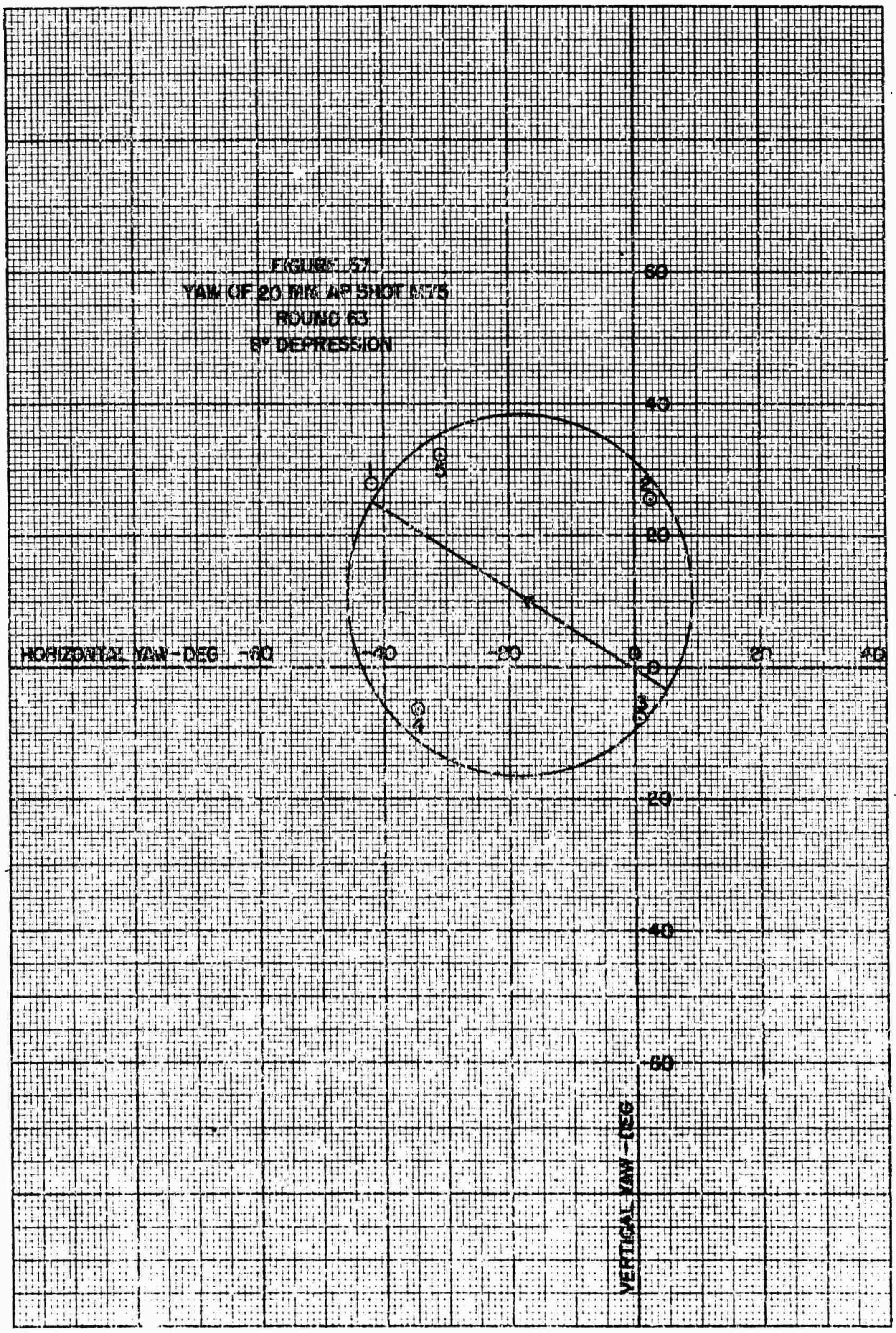


FIGURE 57
YAW OF 20 MM AP SHOT M75
ROUND 63
8° DEPRESSION

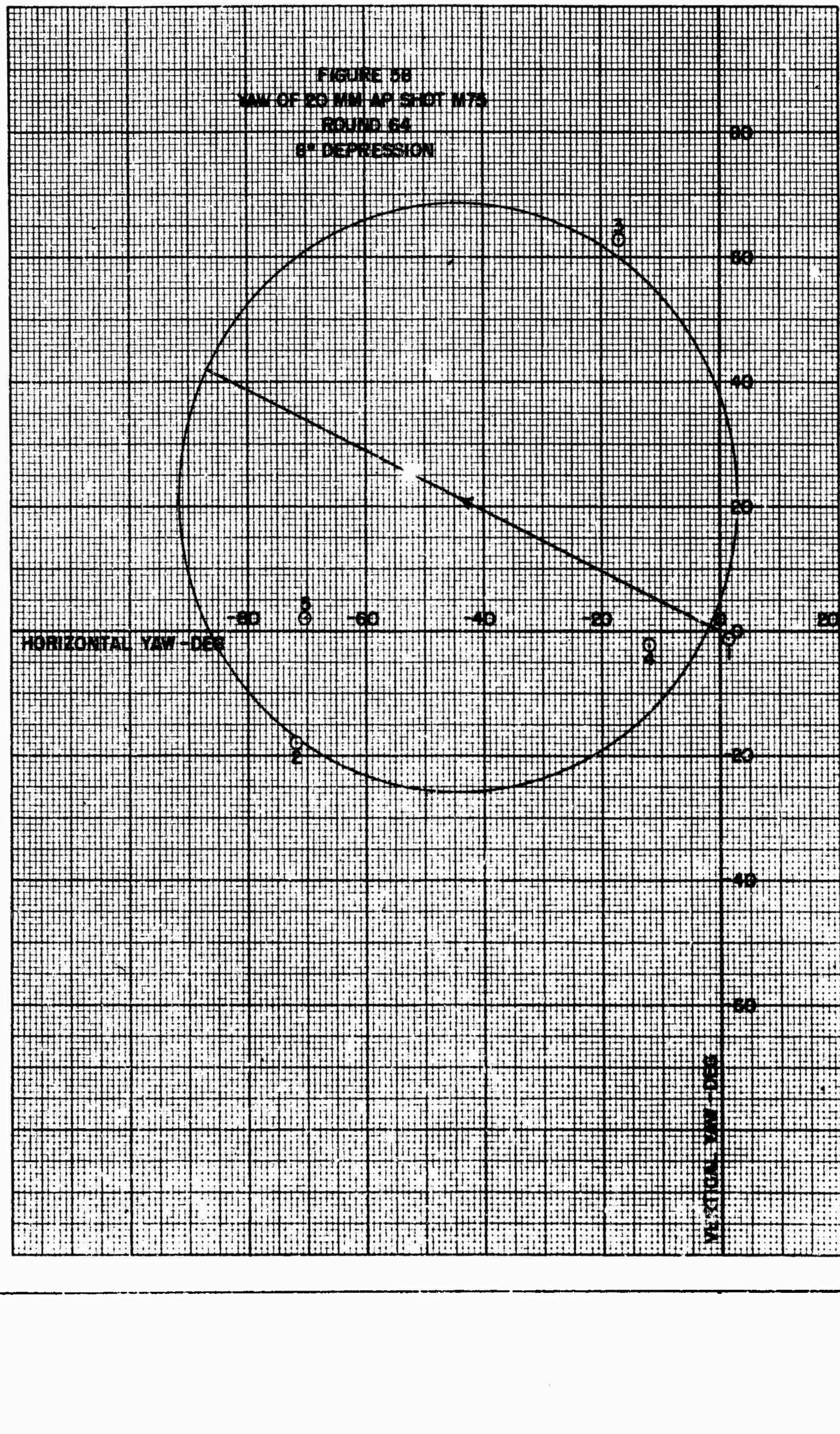


FIGURE 58
YAW OF 20 MM AP SHOT M75
ROUND 64
8° DEPRESSION

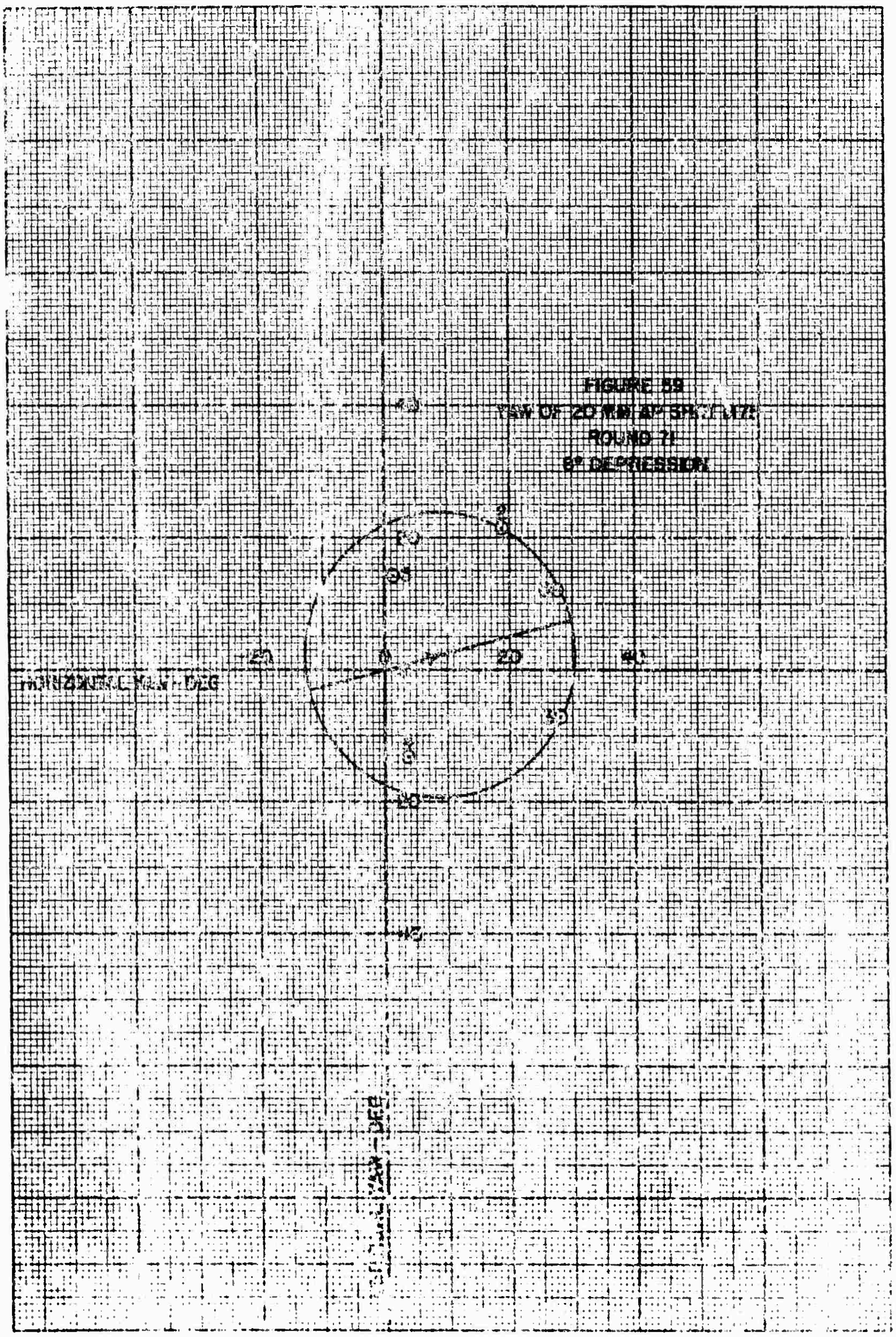


FIGURE 59
YAW OF 20 MM AP SP[illegible]
ROUND 71
8° DEPRESSION

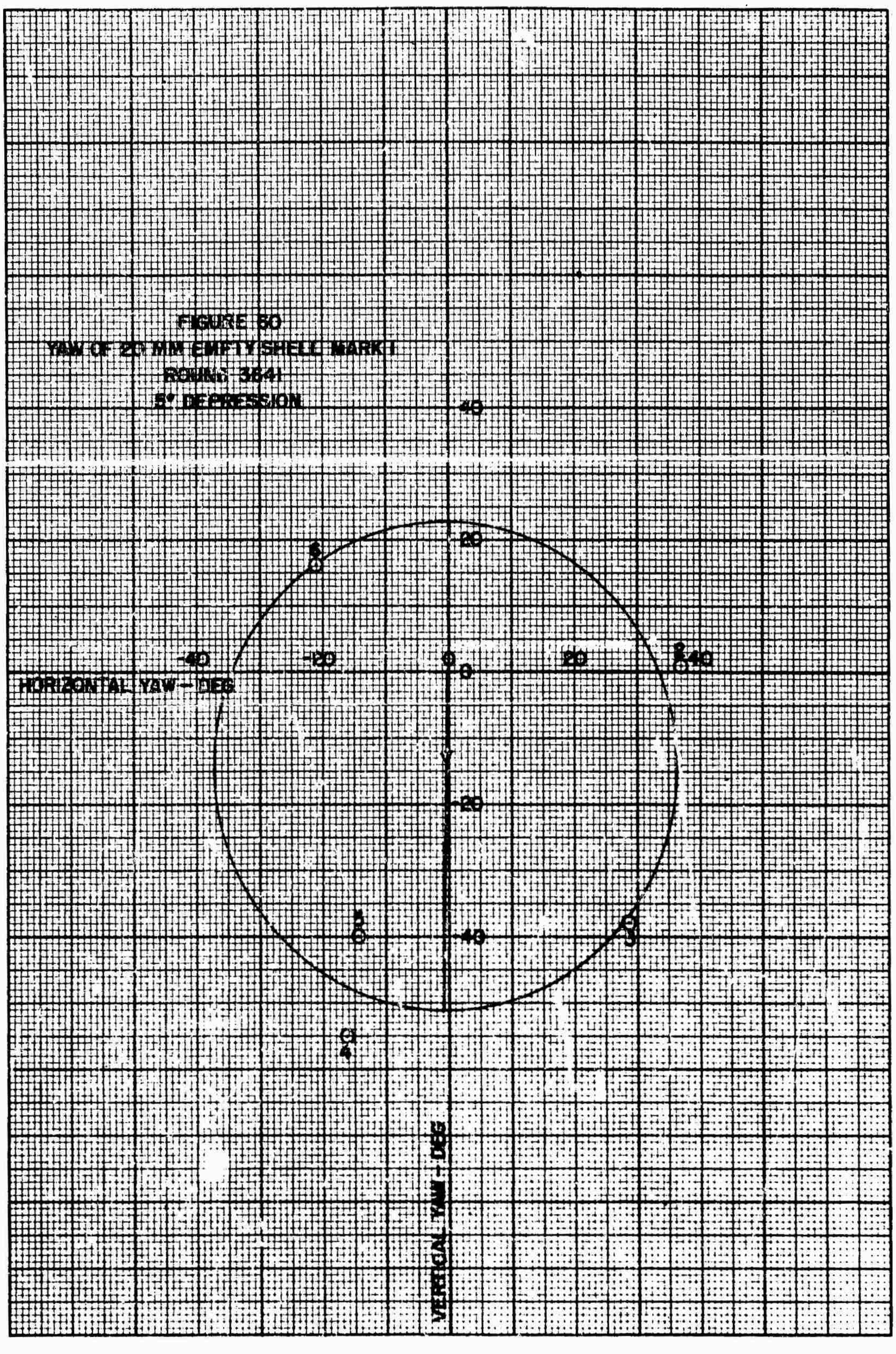


FIGURE 60
YAW OF 20 MM EMPTY SHELL MARK I
ROUND 3641
5° DEPRESSION

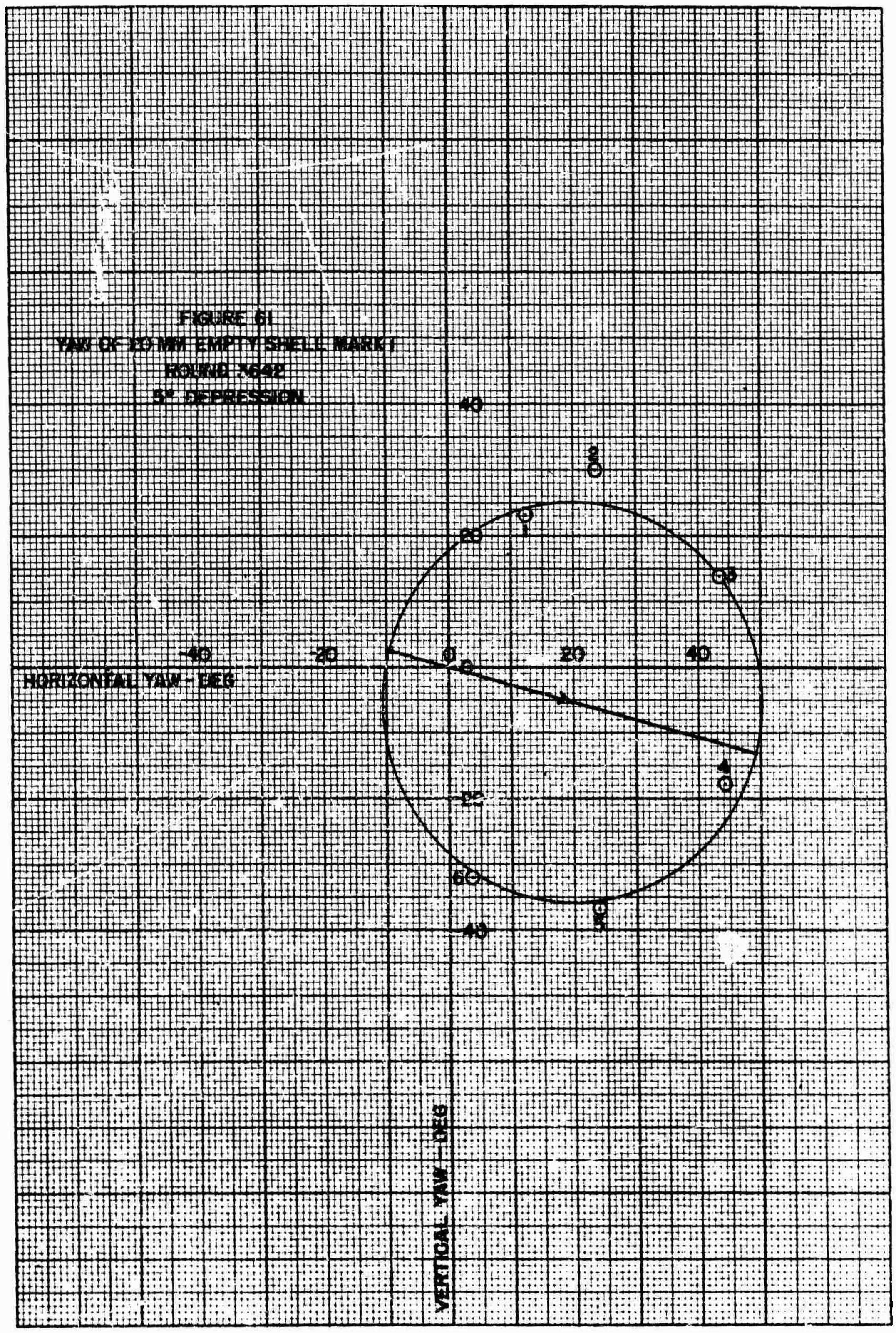


FIGURE 61
YAW OF 20 MM EMPTY SHELL MARK I
ROUND 7642
5° DEPRESSION

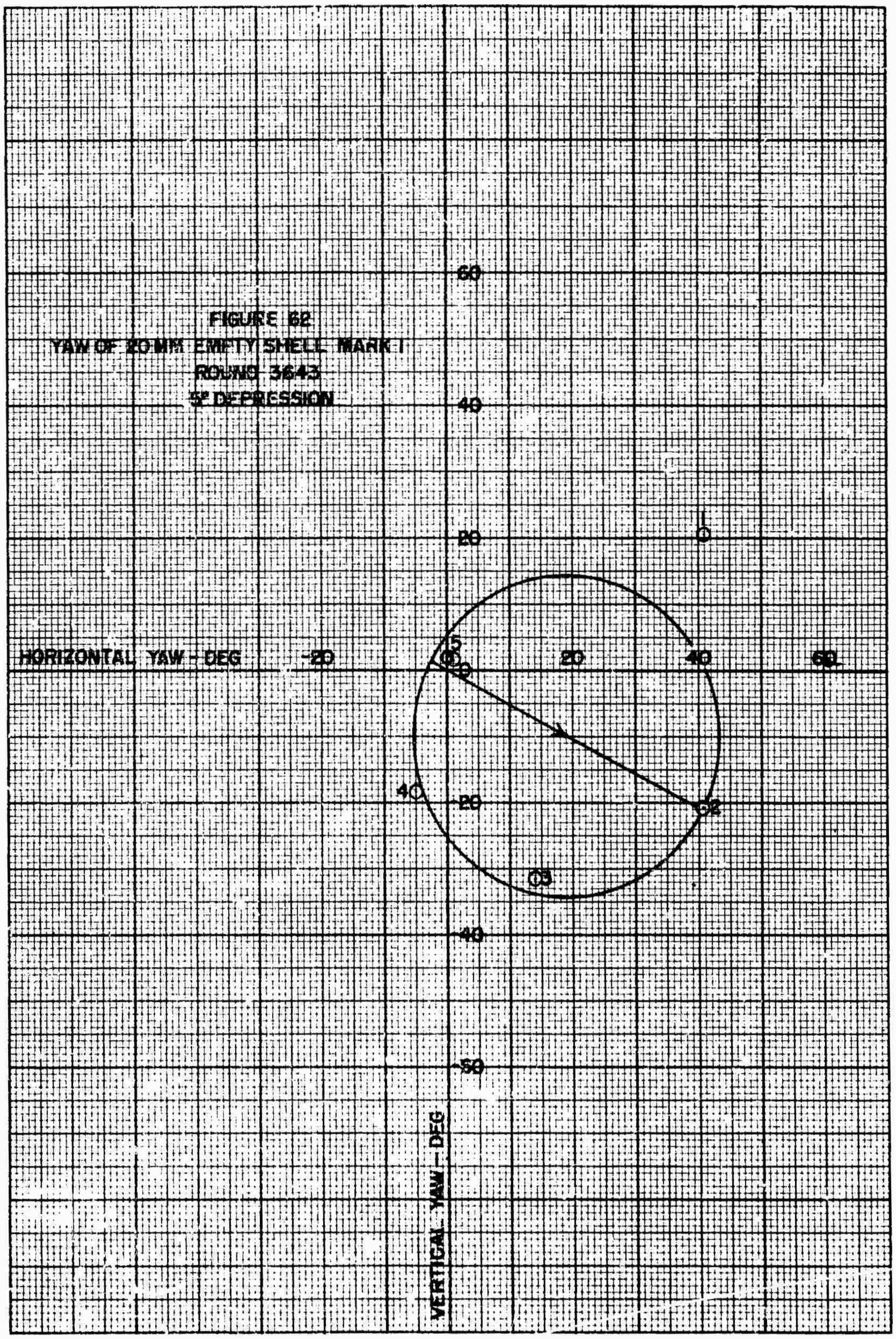


FIGURE 62
YAW OF 20 MM EMPTY SHELL MARK I
ROUND 3643
5° DEPRESSION
HORIZONTAL YAW - DEG
VERTICAL YAW - DEG
60
40
20
-20
-40
-60
-20
20
40
60
1
2
3
4
5

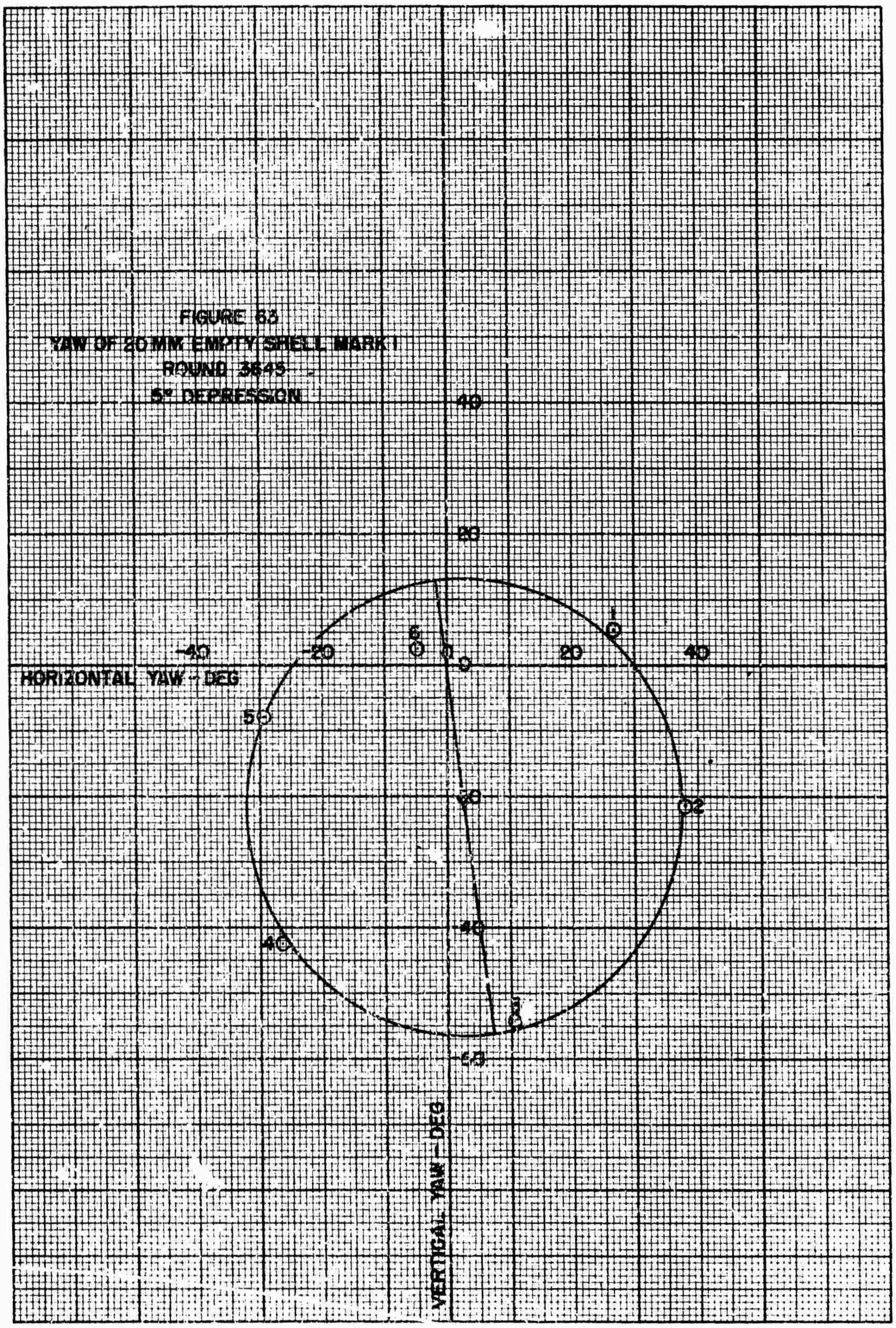


FIGURE 63
YAW OF 20 MM EMPTY SHELL MARK I
ROUND 3645
5° DEPRESSION
HORIZONTAL YAW - DEG
VERTICAL YAW - DEG
-40
-20
20
40
40
20
0
-20
-40
-60
1
2
3
4
5
6
0

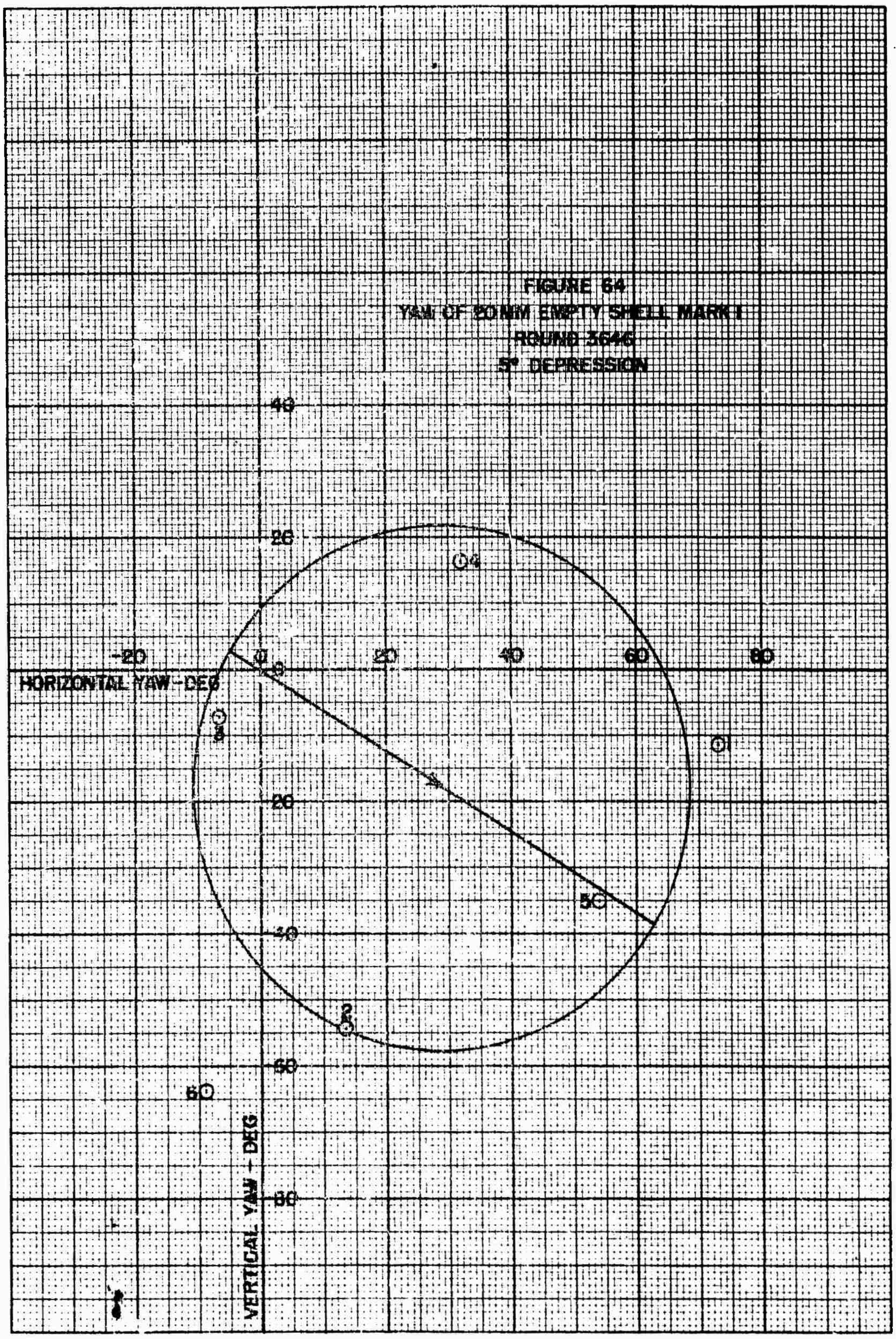


FIGURE 64
YAW OF 20 MM EMPTY SHELL MARK I
ROUND 3646
5° DEPRESSION
HORIZONTAL YAW-DEG
VERTICAL YAW-DEG
-20
0
20
40
60
80
40
20
-20
-40
-60
-80

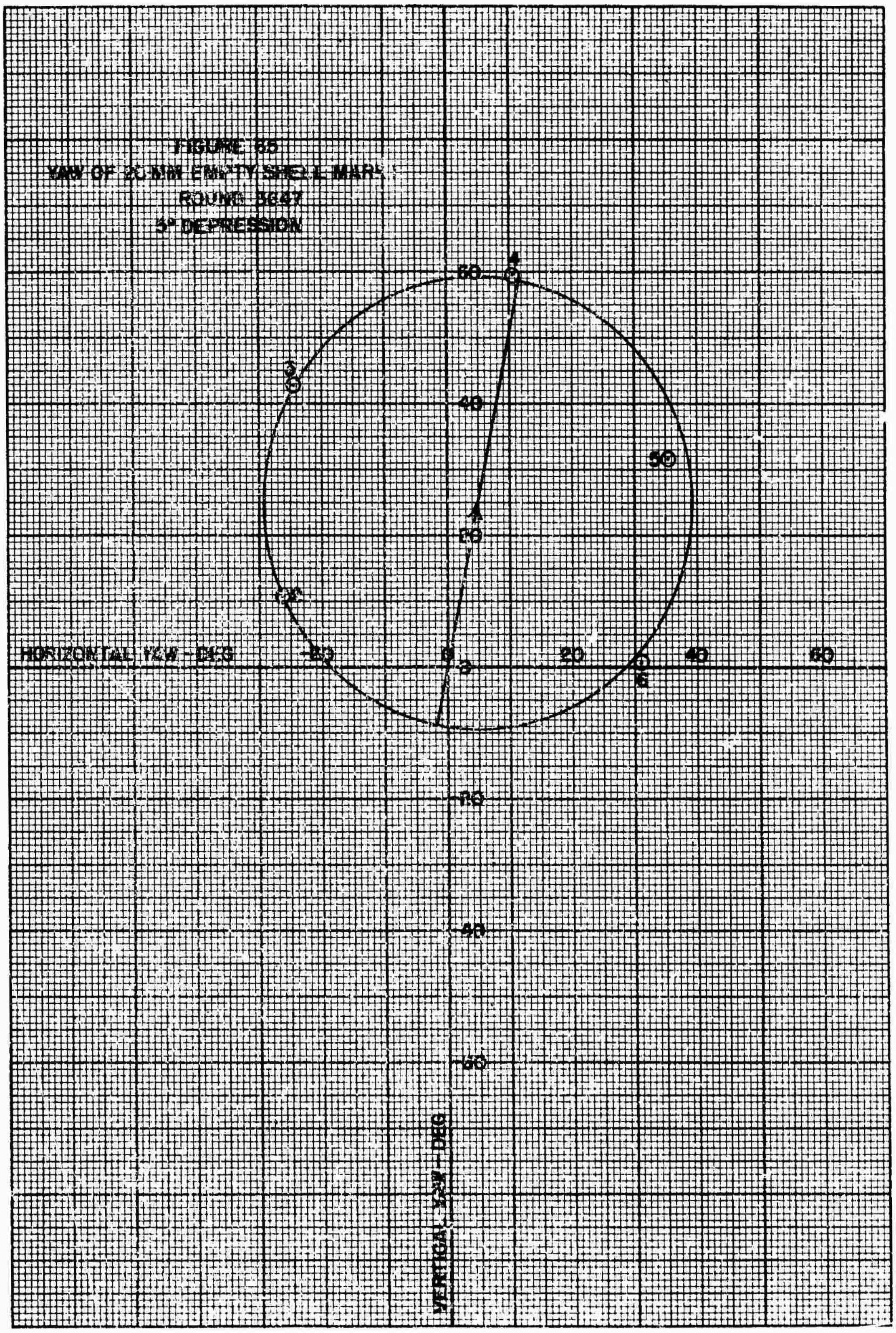


FIGURE 55
YAW OF 20 MM EMPTY SHELL MARK
ROUND 3647
5° DEPRESSION

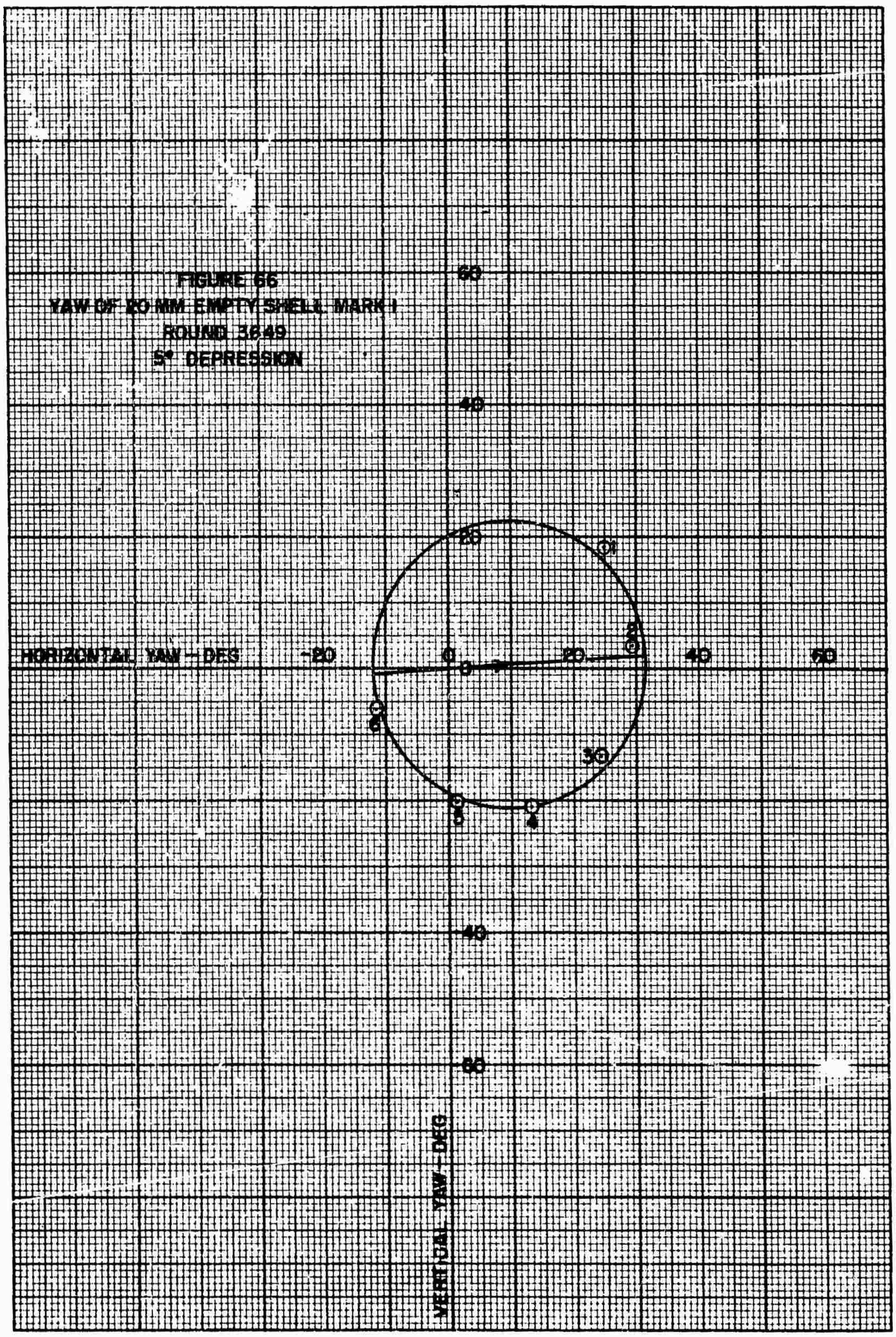


FIGURE 66
YAW OF 20 MM EMPTY SHELL MARK I
ROUND 3649
5° DEPRESSION
HORIZONTAL YAW — DEG
VERTICAL YAW — DEG
-20
0
20
40
60
40
20
40
60

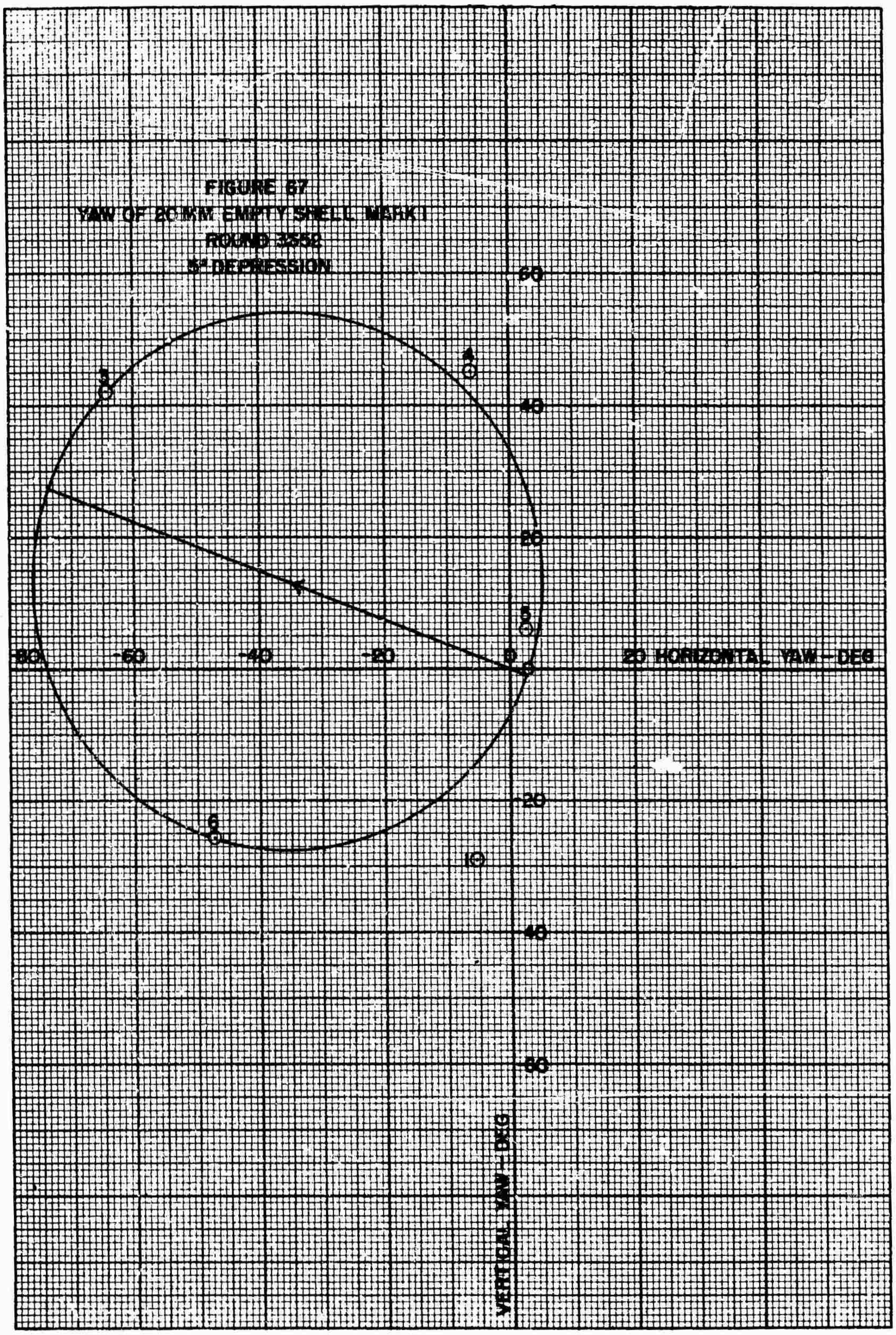


FIGURE 67
YAW OF 20 MM EMPTY SHELL MARK I
ROUND 3552
5° DEPRESSION

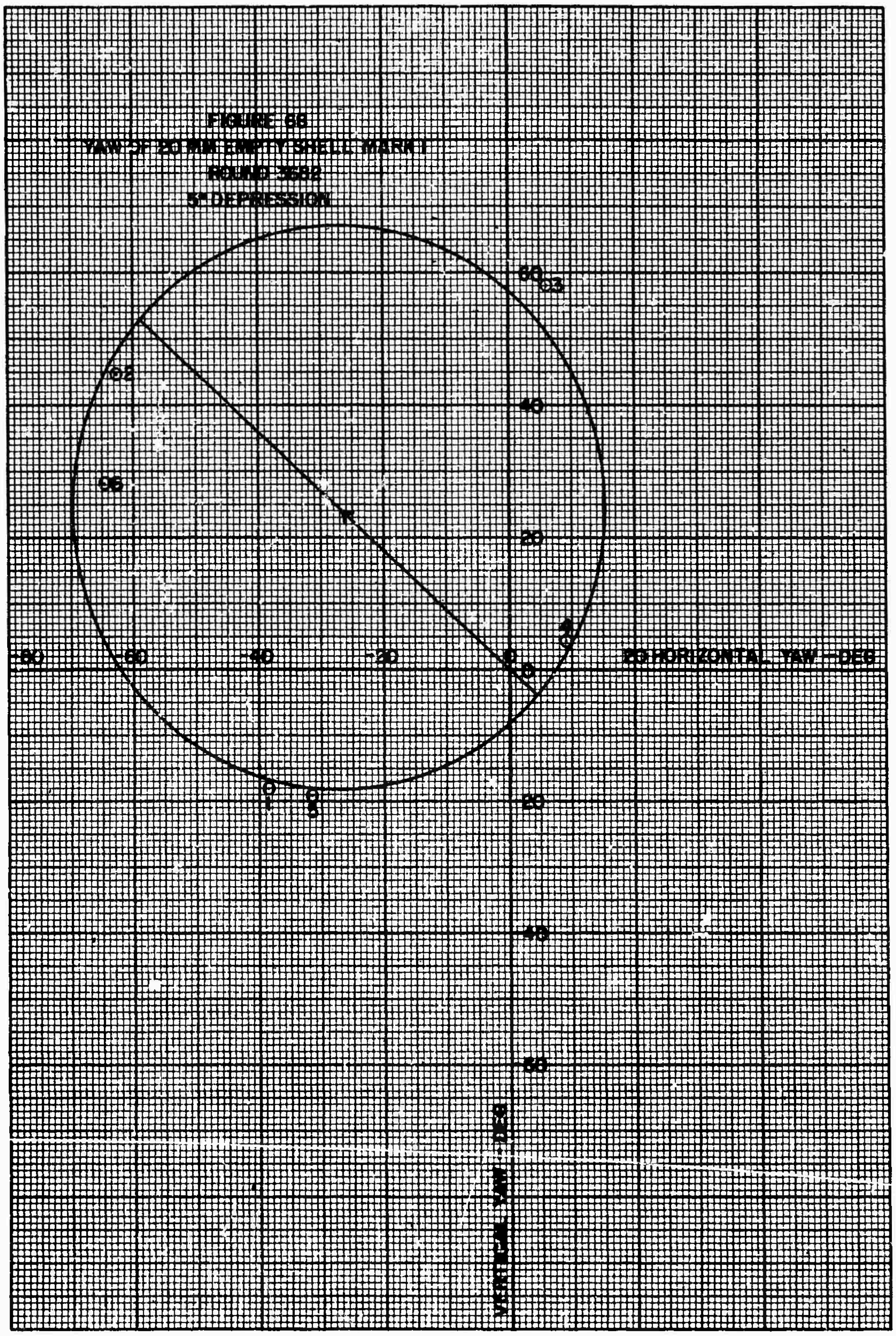


FIGURE 68
YAW OF 20 MM EMPTY SHELL MARK I
ROUND 3682
5° DEPRESSION

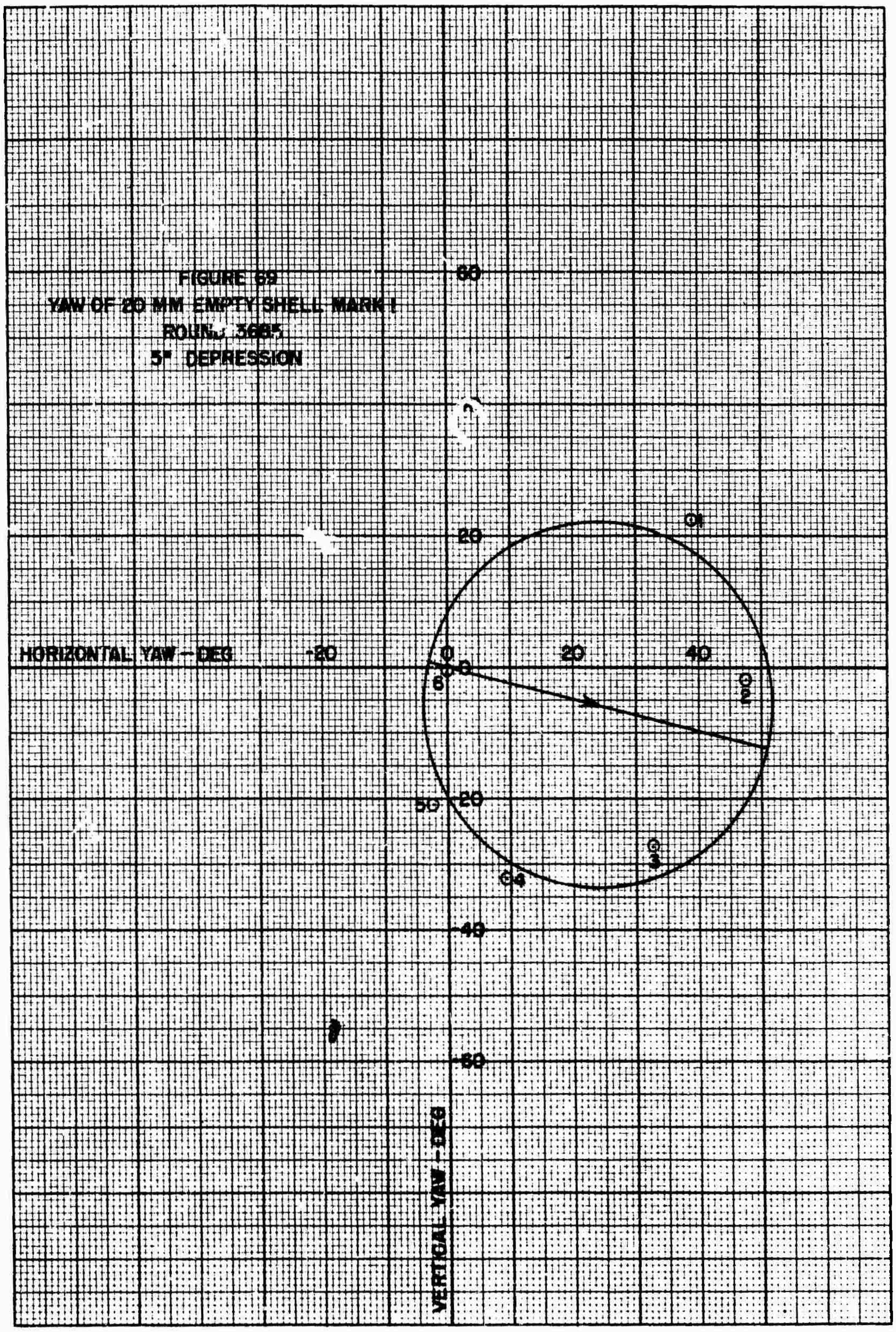


FIGURE 69
YAW OF 20 MM EMPTY SHELL MARK I
ROUND 3685
5° DEPRESSION
HORIZONTAL YAW – DEG
VERTICAL YAW – DEG
-20
0
20
40
60
20
-20
-40
-60
1
2
3
4
5
6

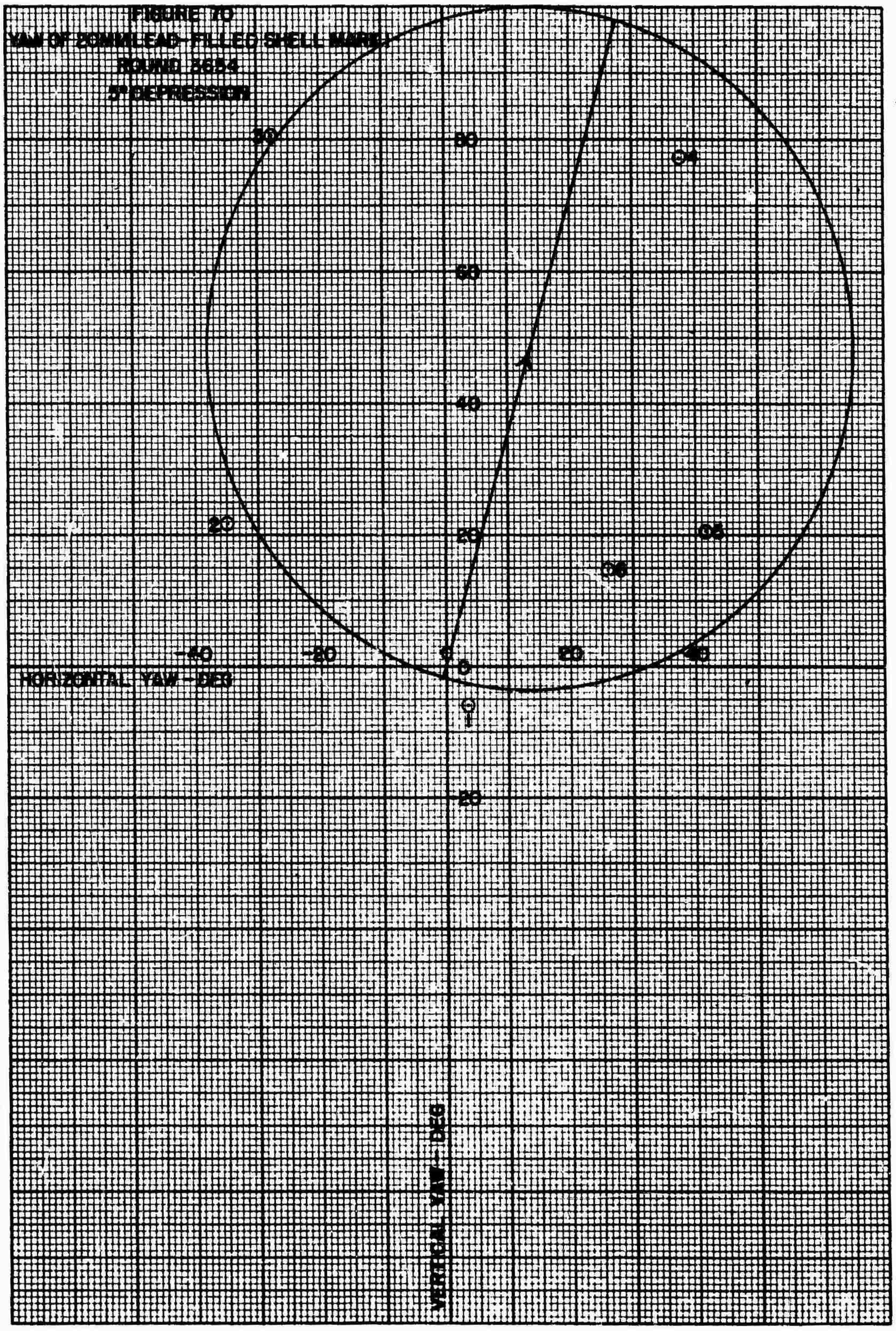


FIGURE 70
YAW OF 20MM LEAD-FILLED SHELL MARK
ROUND 3654
5° DEPRESSION
HORIZONTAL YAW - DEG
VERTICAL YAW - DEG
-40
-20
0
20
40
80
60
40
20
-20

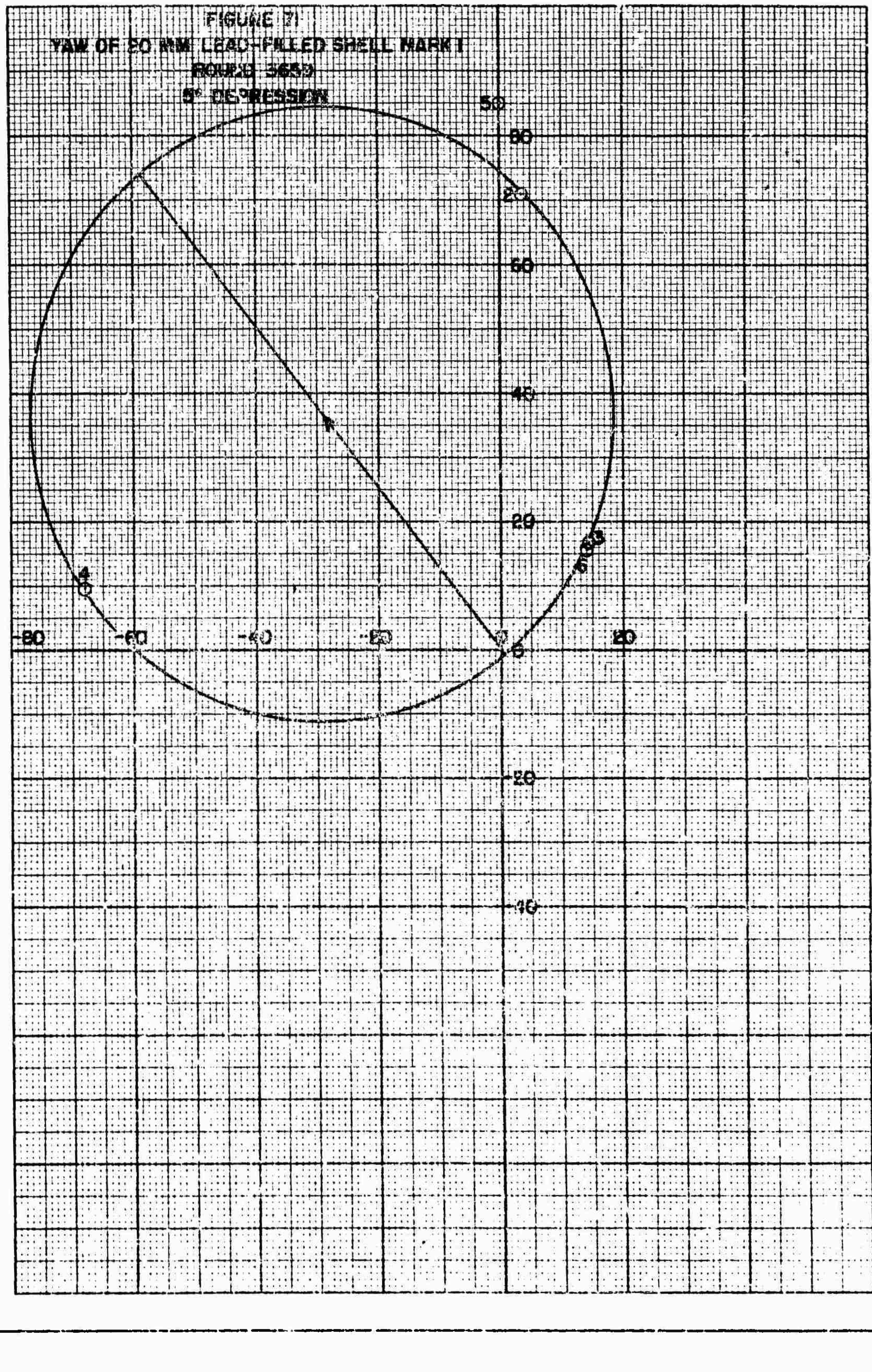


FIGURE 71
YAW OF 20 MM LEAD-FILLED SHELL MARK I
ROUND 3659
5° DEPRESSION

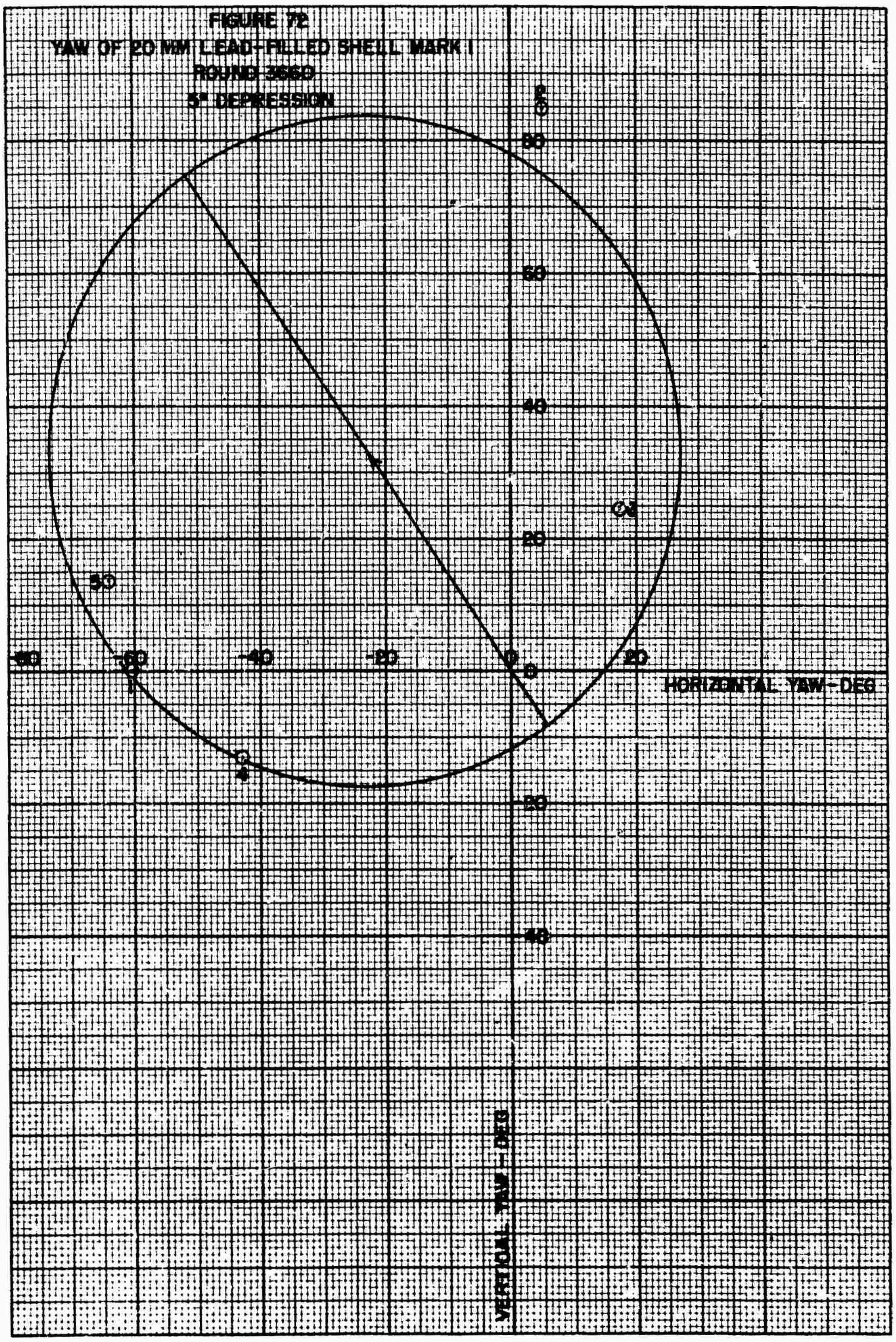


FIGURE 72
YAW OF 20 MM LEAD-FILLED SHELL MARK I
ROUND 3660
5° DEPRESSION
HORIZONTAL YAW-DEG
VERTICAL YAW-DEG
80
60
40
20
0
-20
-40
-80
-60
-40
-20
20
50
2
1
4

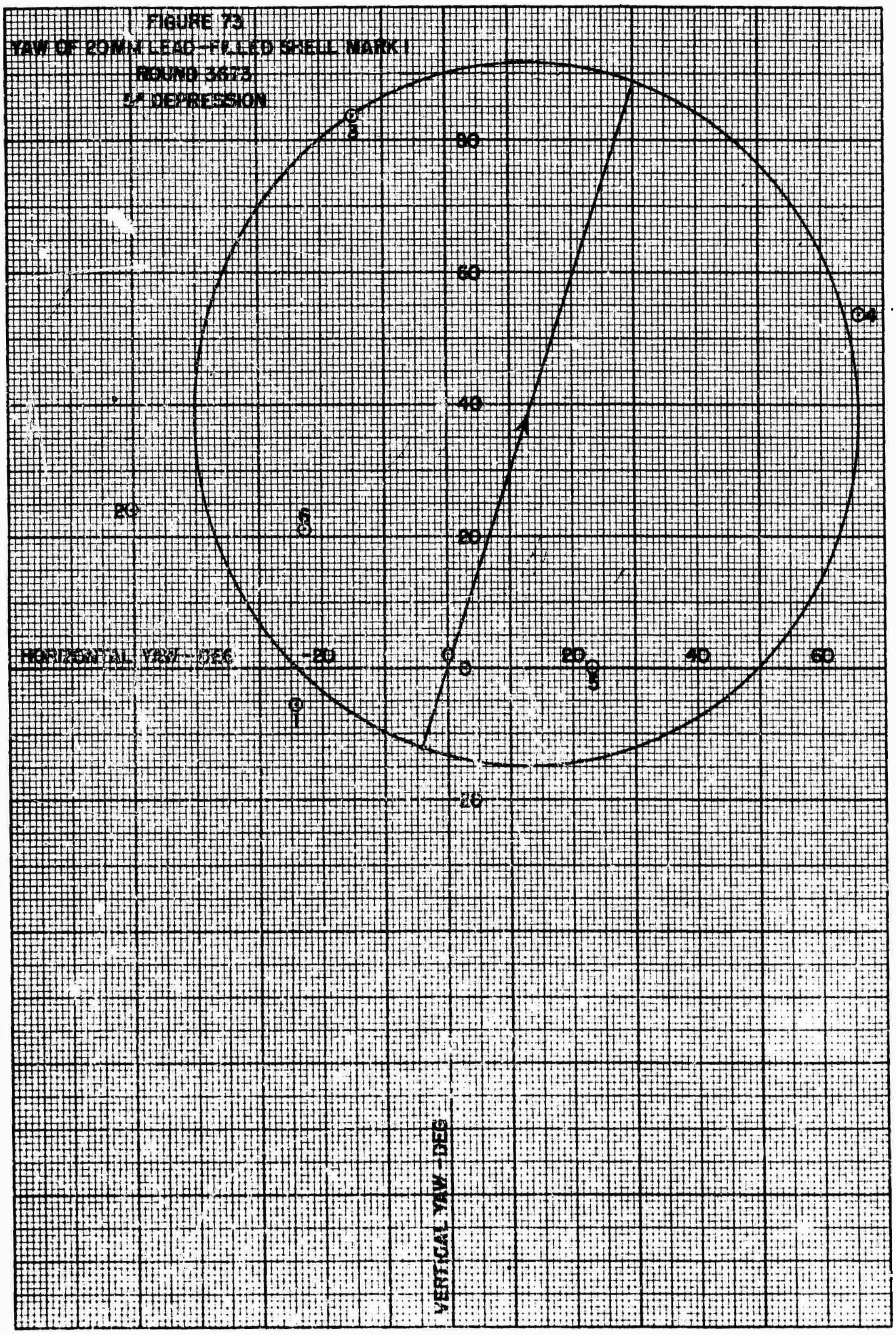


FIGURE 73
YAW OF 20MM LEAD-FILLED SHELL MARK I
ROUND 3673
5° DEPRESSION
HORIZONTAL YAW - DEG
VERTICAL YAW - DEG
80
60
40
20
0
-20
-20
20
40
60
1
2
3
4
5
6

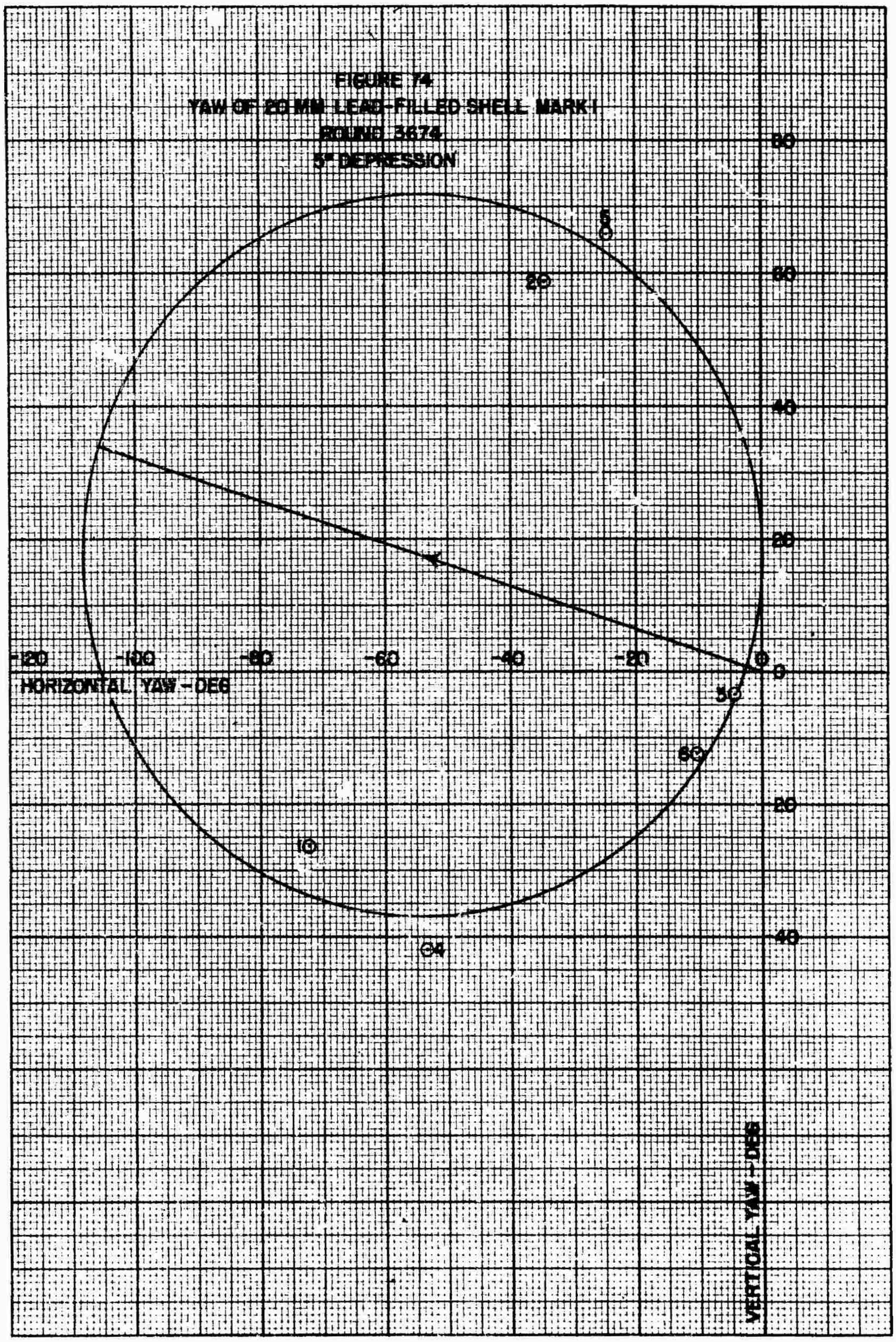


FIGURE 74
YAW OF 20 MM LEAD-FILLED SHELL MARK I
ROUND 3674
5° DEPRESSION

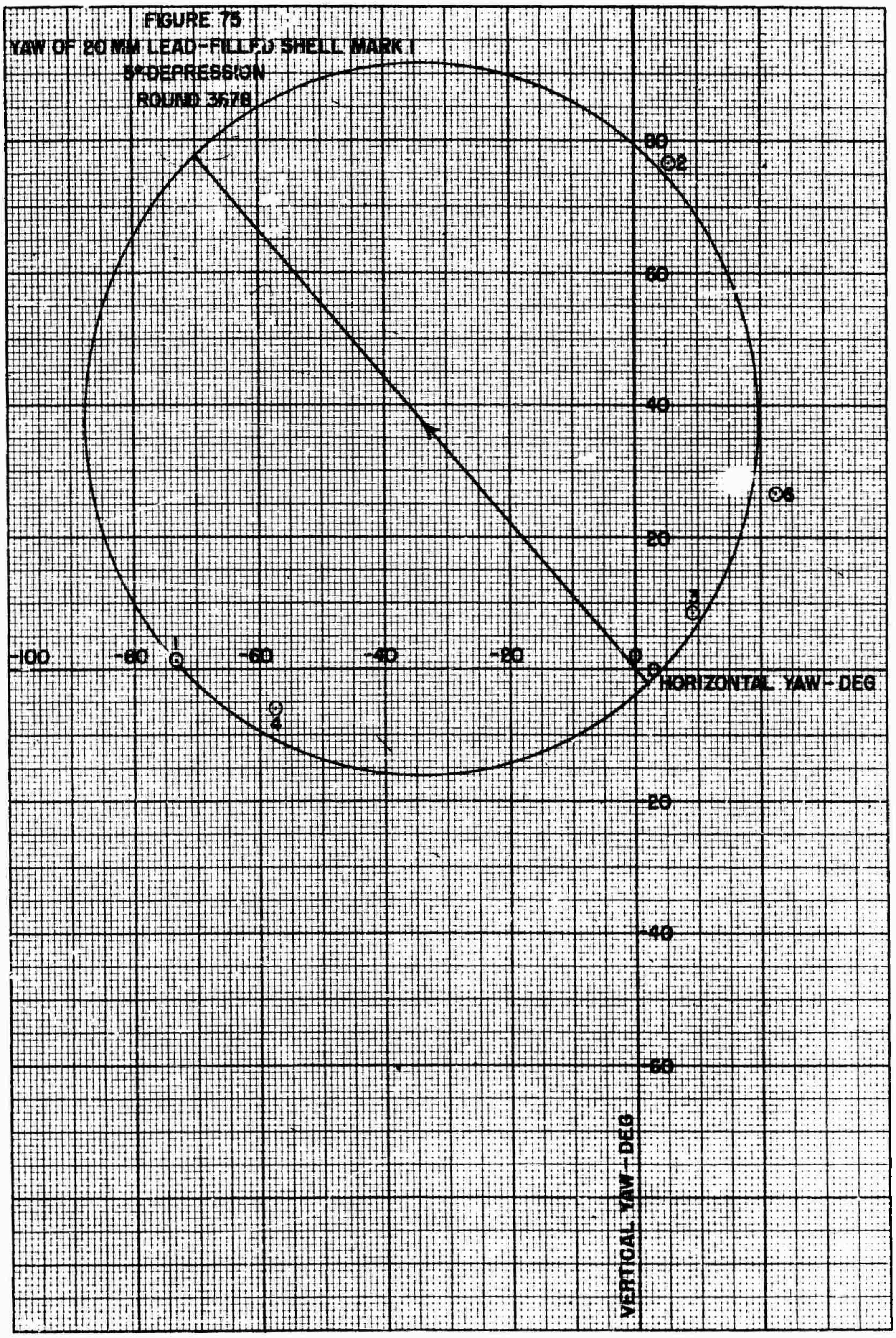


FIGURE 75
YAW OF 20 MM LEAD-FILLED SHELL MARK I
5° DEPRESSION
ROUND 3578
80
60
40
20
-20
-40
-60
-100
-80
-60
-40
-20
HORIZONTAL YAW - DEG
VERTICAL YAW - DEG
1
2
3
4
5

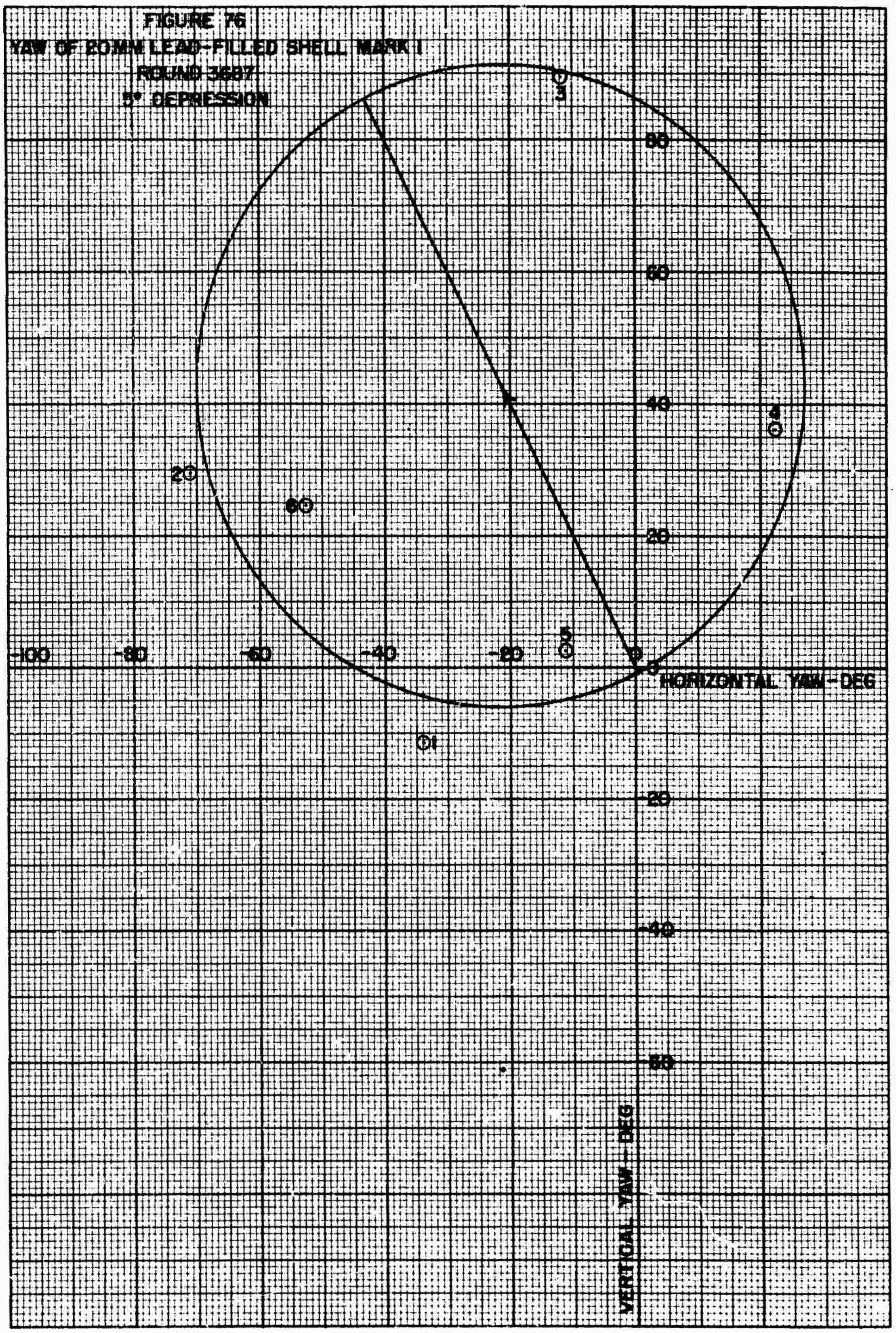


FIGURE 76
YAW OF 20-MM LEAD-FILLED SHELL MARK I
ROUND 3687
5° DEPRESSION
80
60
40
20
0
-20
-40
-60
-100
-80
-60
-40
-20
HORIZONTAL YAW-DEG
VERTICAL YAW-DEG
1
2
3
4
5
6

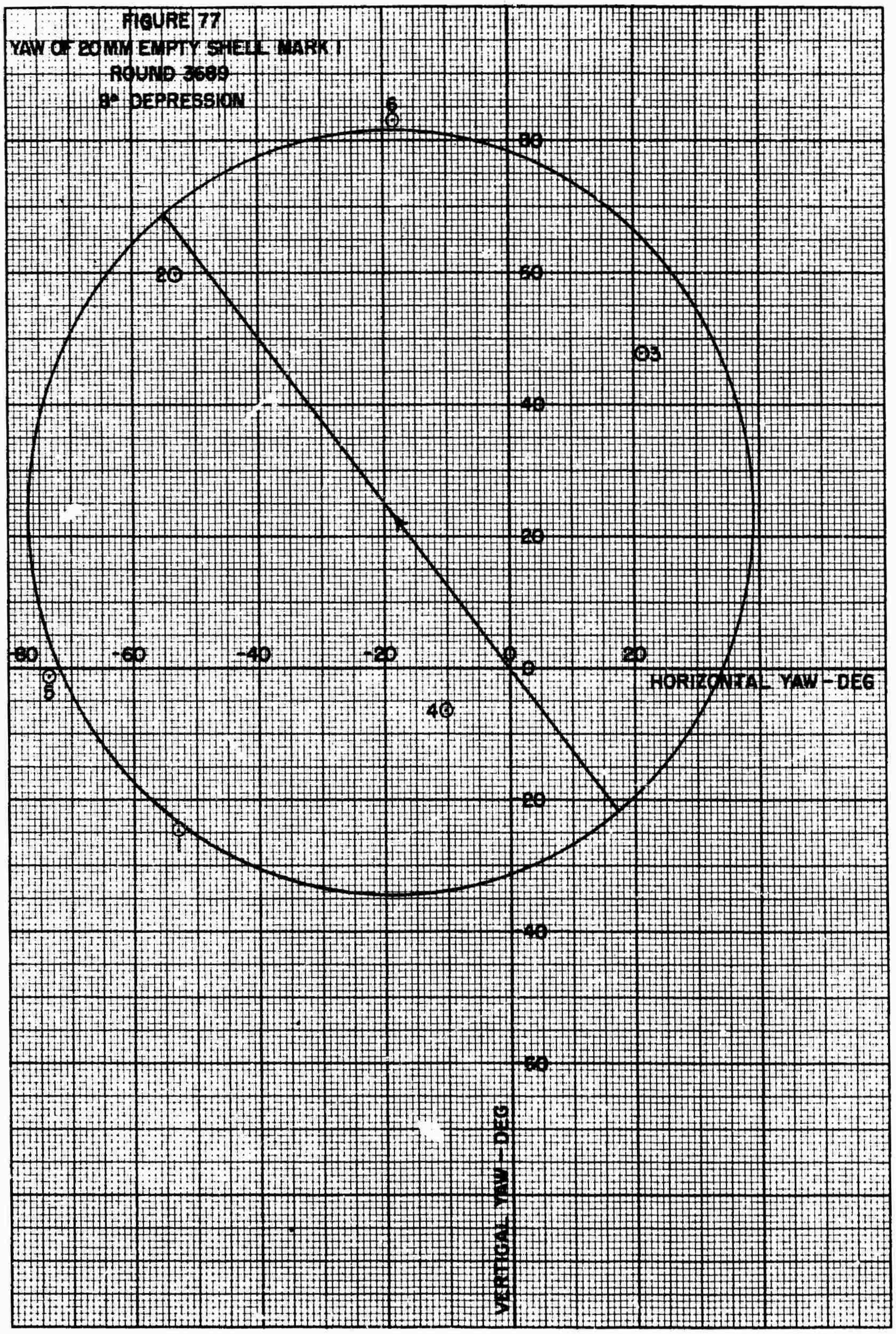
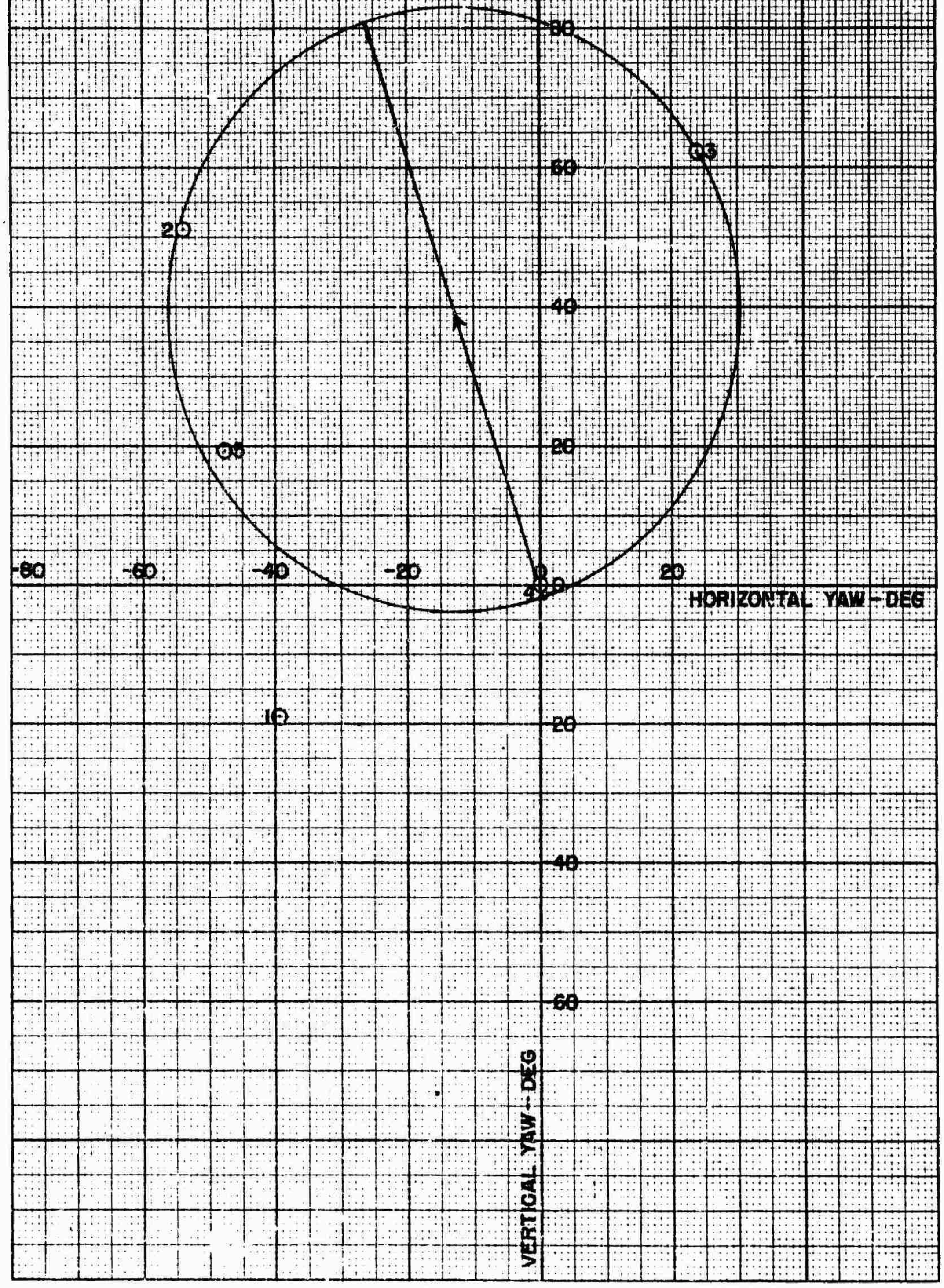


FIGURE 77
YAW OF 20MM EMPTY SHELL MARK I
ROUND 3689
8° DEPRESSION
80
60
40
20
0
-20
-40
-60
-80
-60
-40
-20
20
HORIZONTAL YAW - DEG
VERTICAL YAW - DEG
1
2
3
4
5
6

FIGURE 78
YAW OF 20 MM EMPTY SHELL MARK I
ROUND 3691
8° DEPRESSION



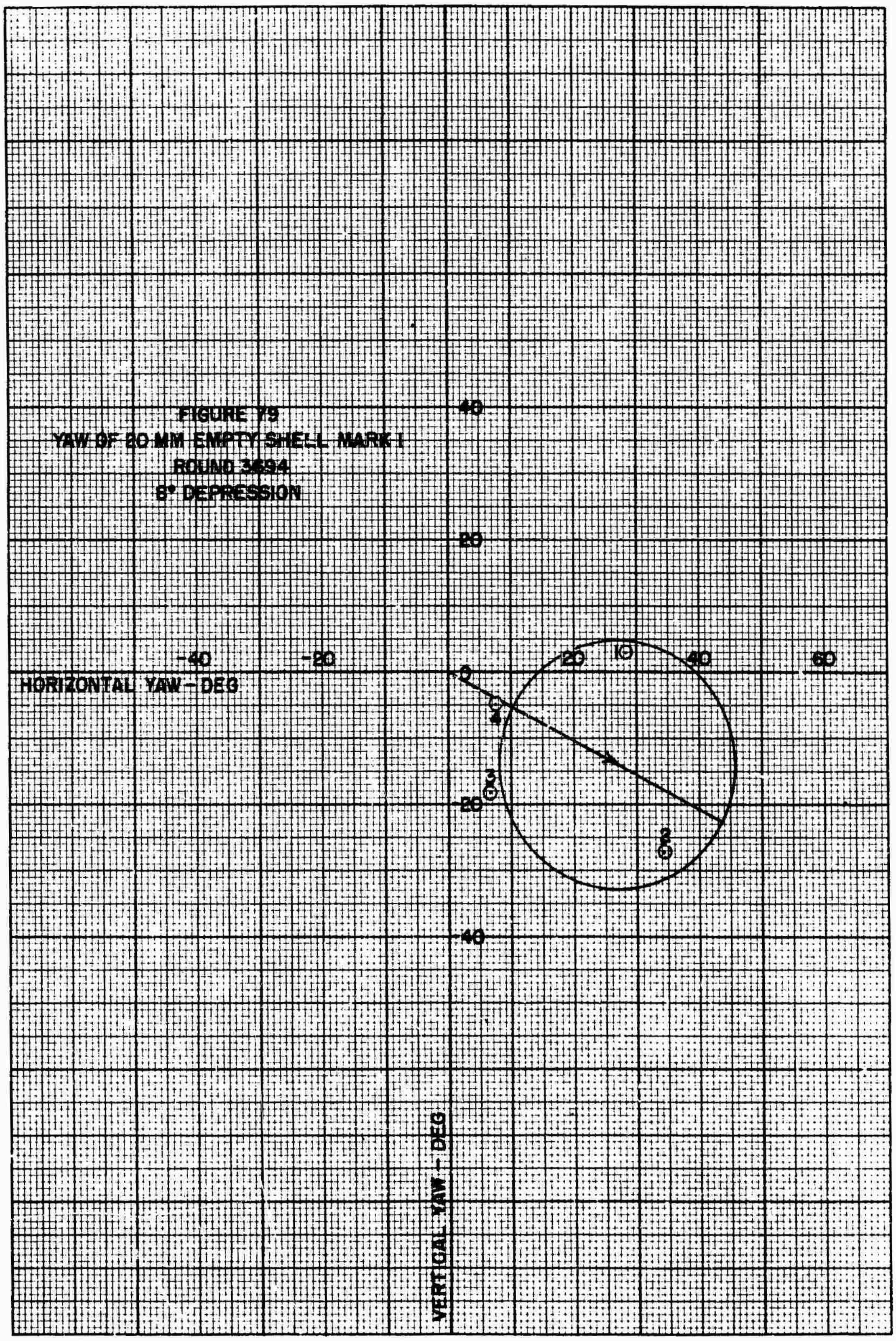


FIGURE 79
YAW OF 20 MM EMPTY SHELL MARK I
ROUND 3694
8° DEPRESSION
40
20
-40
-20
0
20
40
60
HORIZONTAL YAW - DEG
-20
-40
VERTICAL YAW - DEG

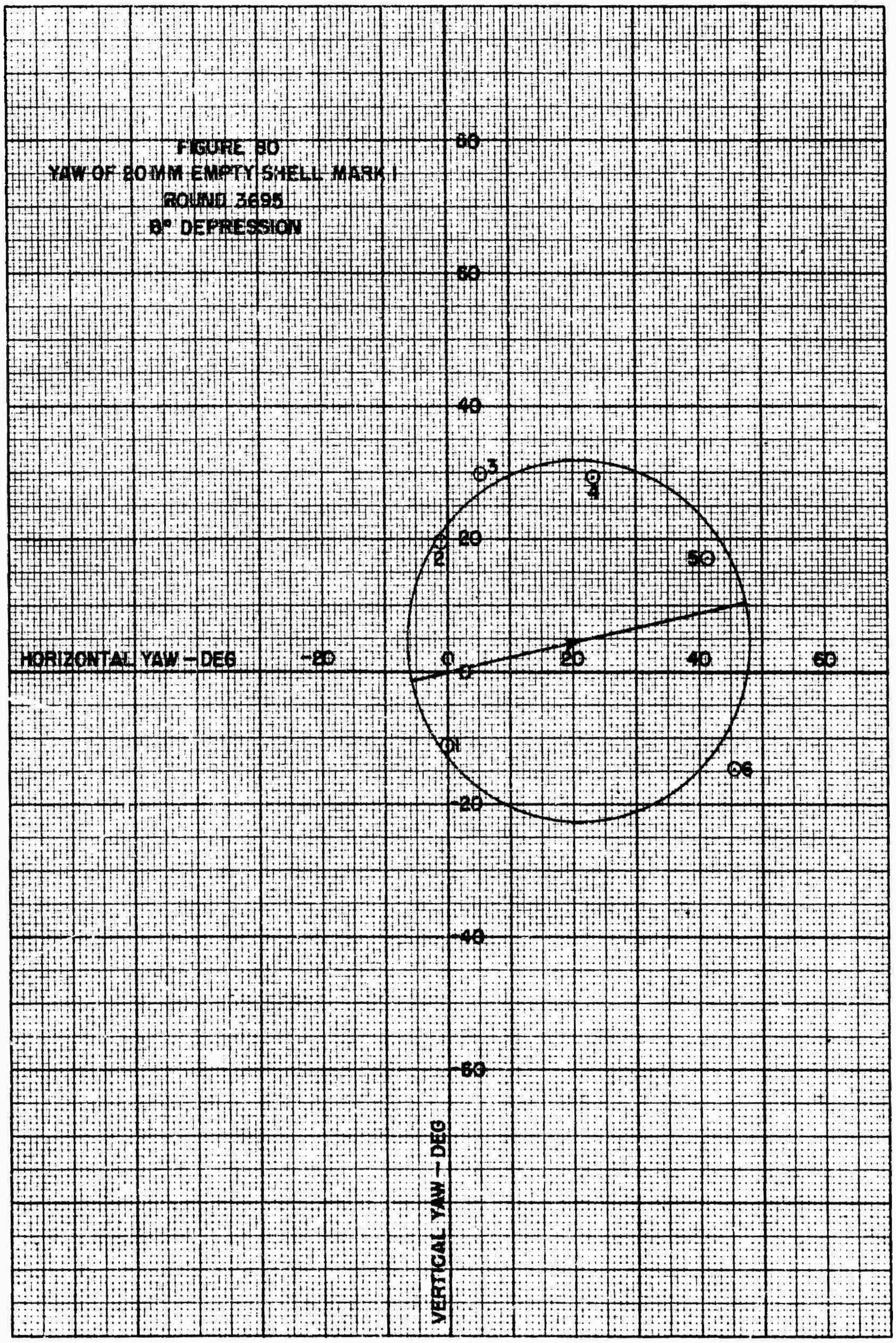


FIGURE 80
YAW OF 20 MM EMPTY SHELL MARK I
ROUND 3695
8° DEPRESSION

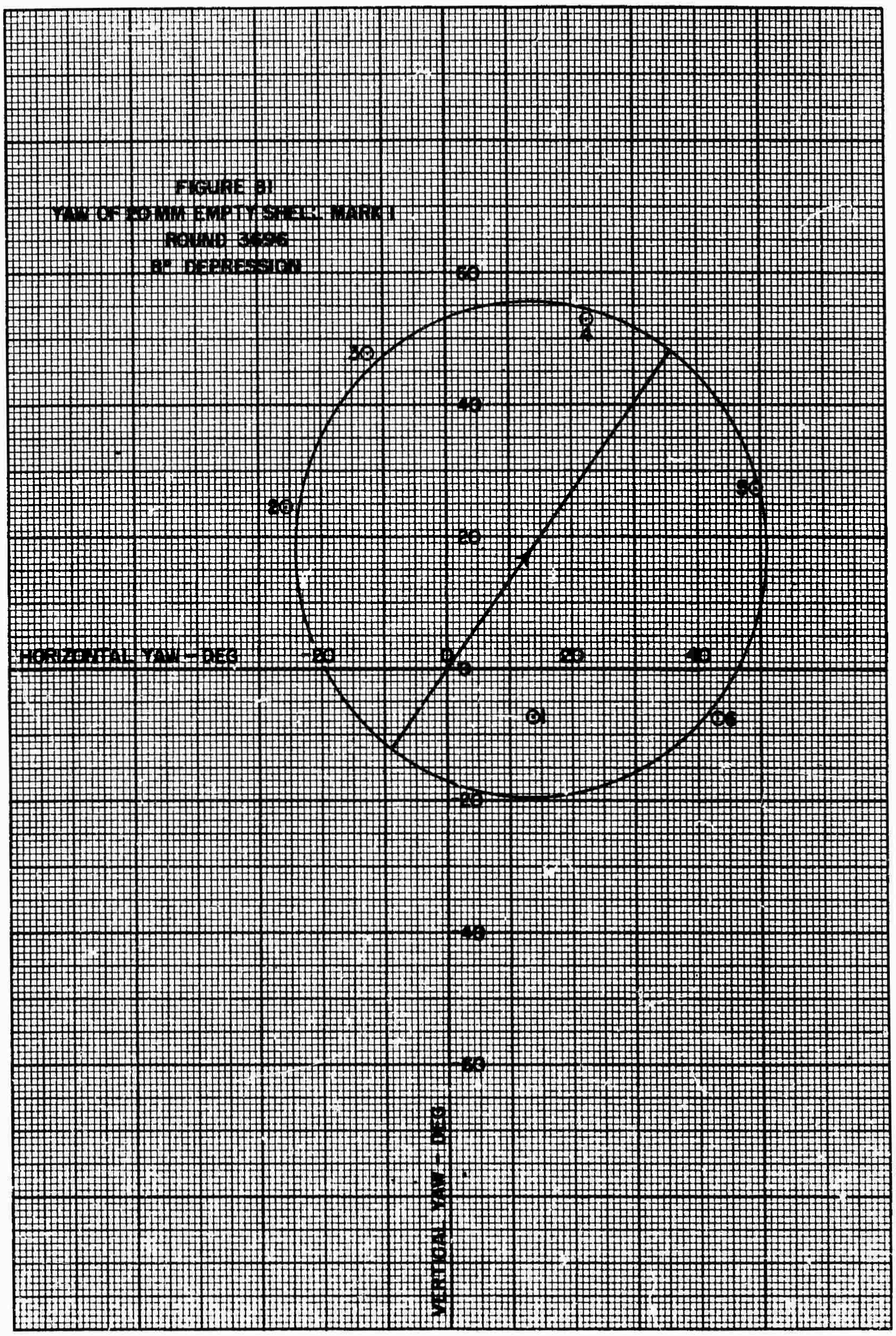


FIGURE 81
YAW OF 20 MM EMPTY SHELL: MARK I
ROUND 3496
8° DEPRESSION
HORIZONTAL YAW – DEG
VERTICAL YAW – DEG
60
40
20
-20
0
20
40
20
40
60

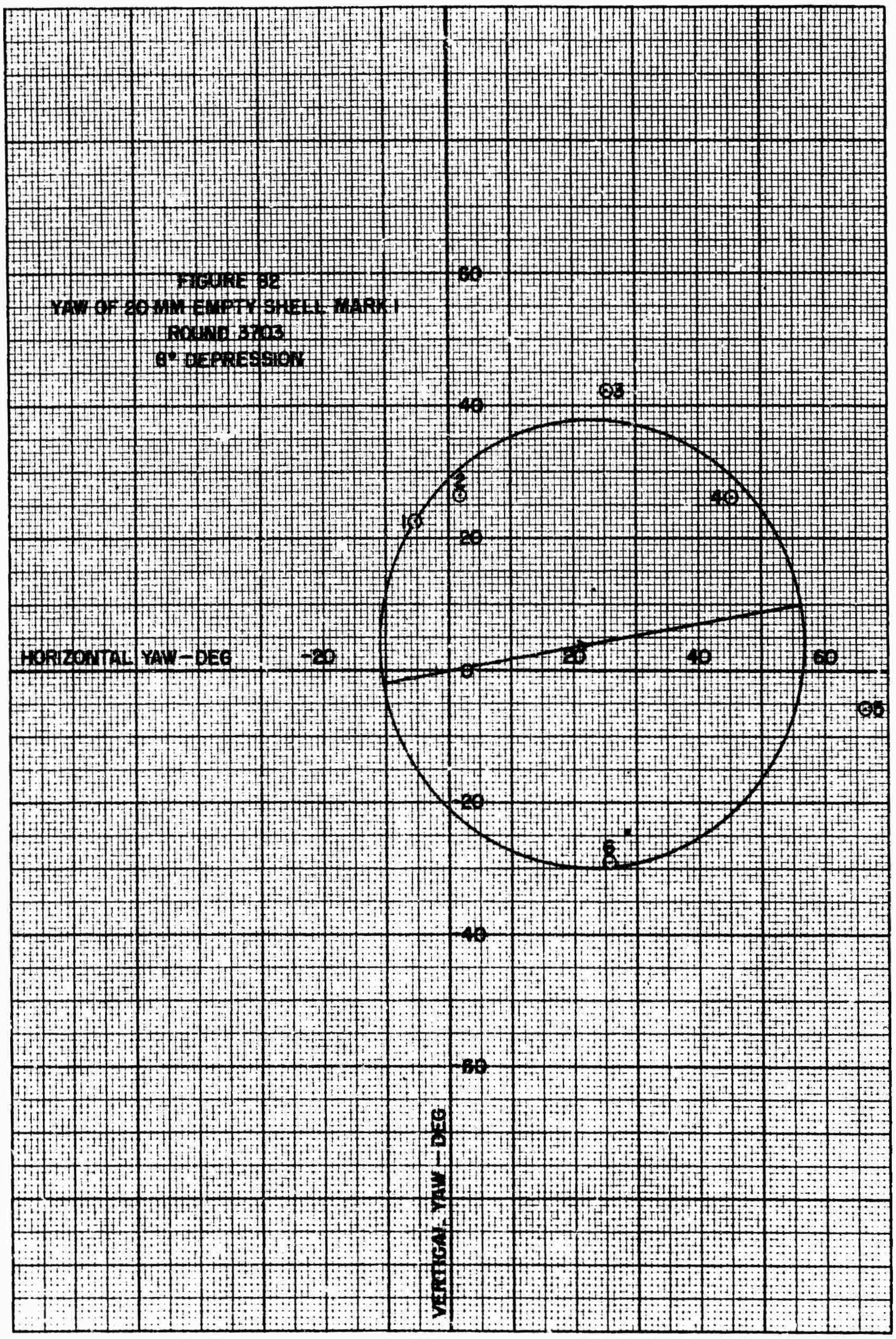


FIGURE 82
YAW OF 20 MM EMPTY SHELL MARK I
ROUND 3703
6° DEPRESSION

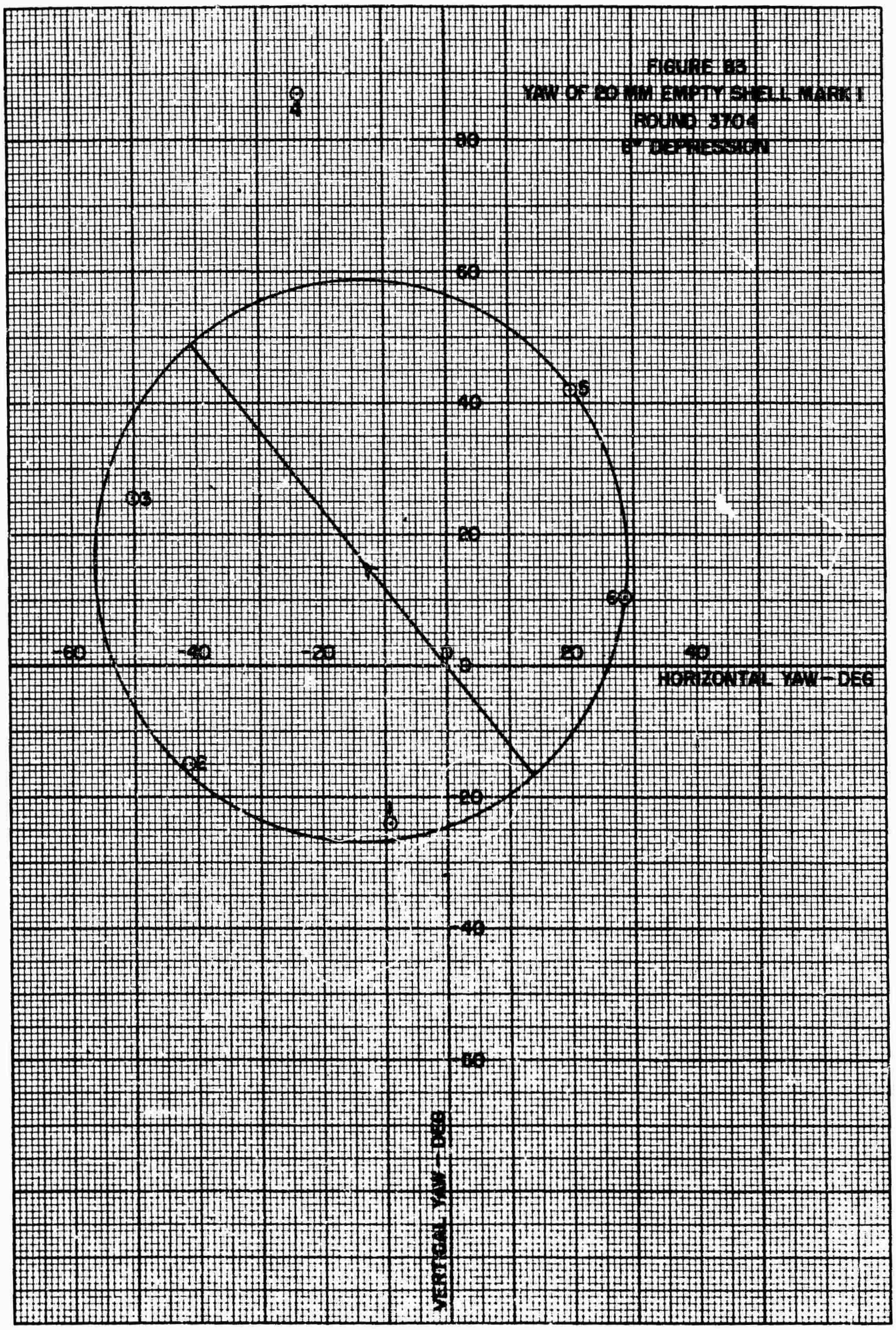


FIGURE 83
YAW OF 20 MM EMPTY SHELL MARK I
ROUND 3704
8° DEPRESSION
80
60
40
20
0
-20
-40
-60
-60
-40
-20
20
40
HORIZONTAL YAW – DEG
VERTICAL YAW – DEG

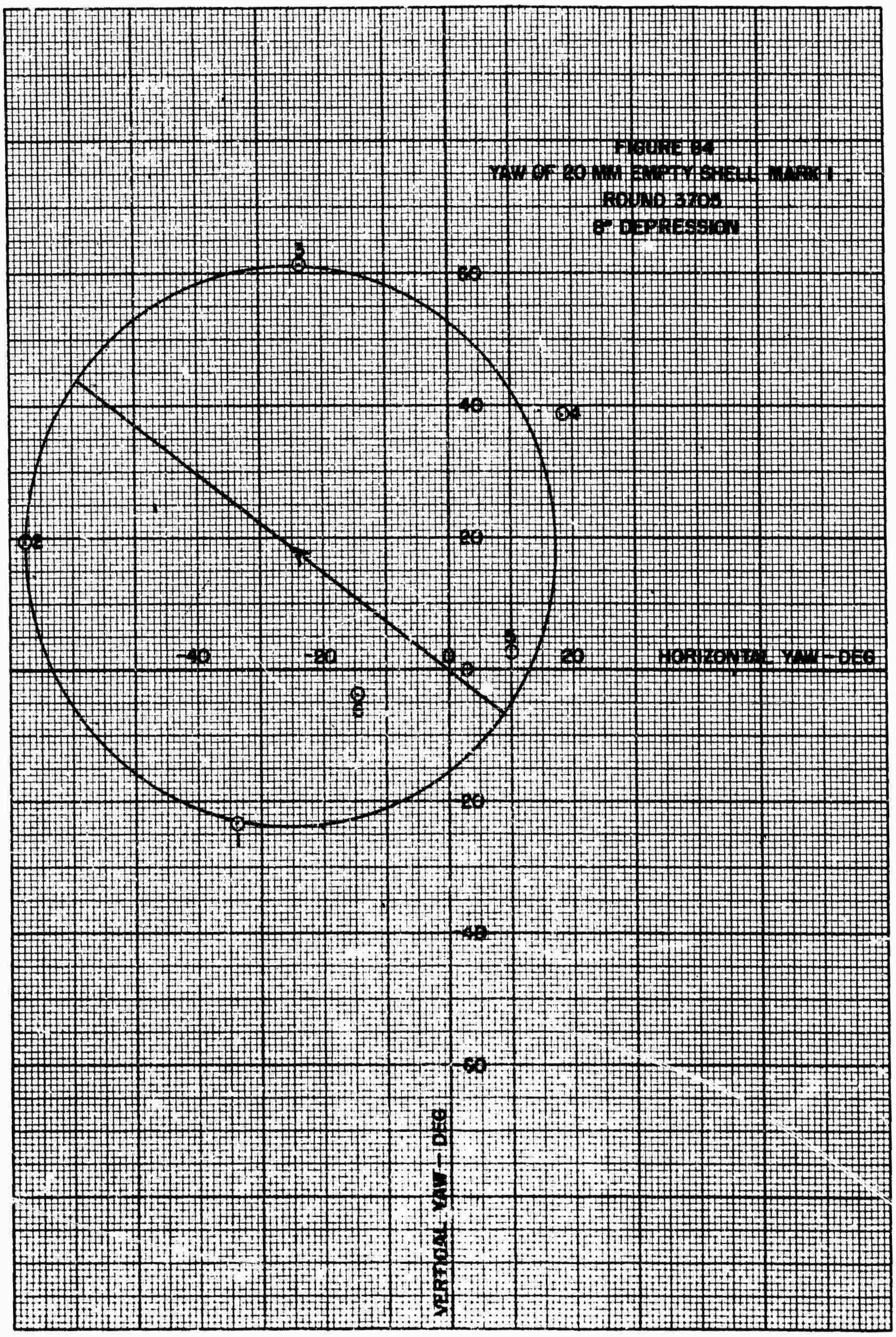


FIGURE 84
YAW OF 20 MM EMPTY SHELL MARK I
ROUND 3705
6° DEPRESSION

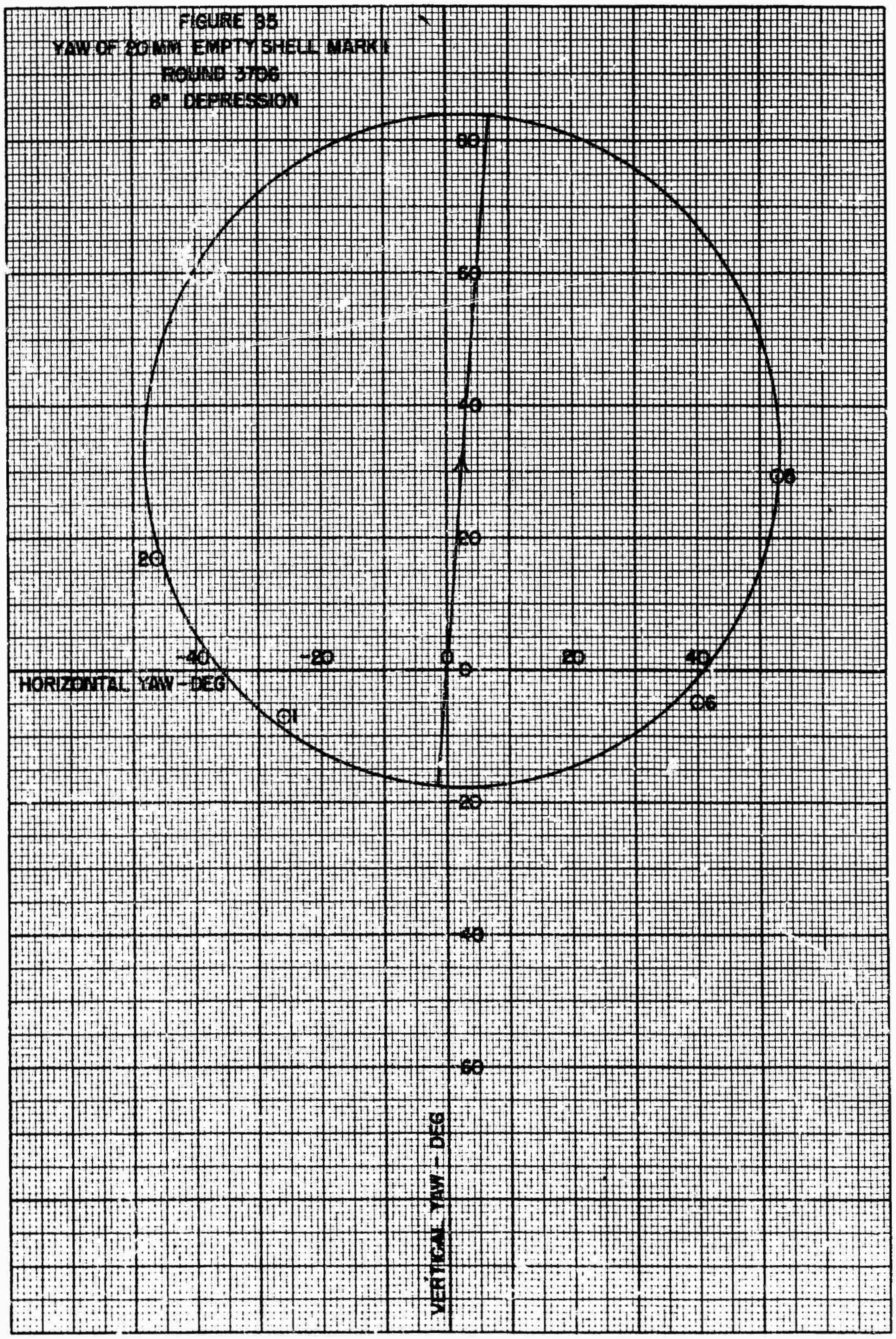


FIGURE 35
YAW OF 20 MM EMPTY SHELL MARK I
ROUND 3706
8° DEPRESSION
80
60
40
20
0
-20
-40
-60
-40
-20
20
40
HORIZONTAL YAW - DEG
VERTICAL YAW - DEG
1
2
5
6

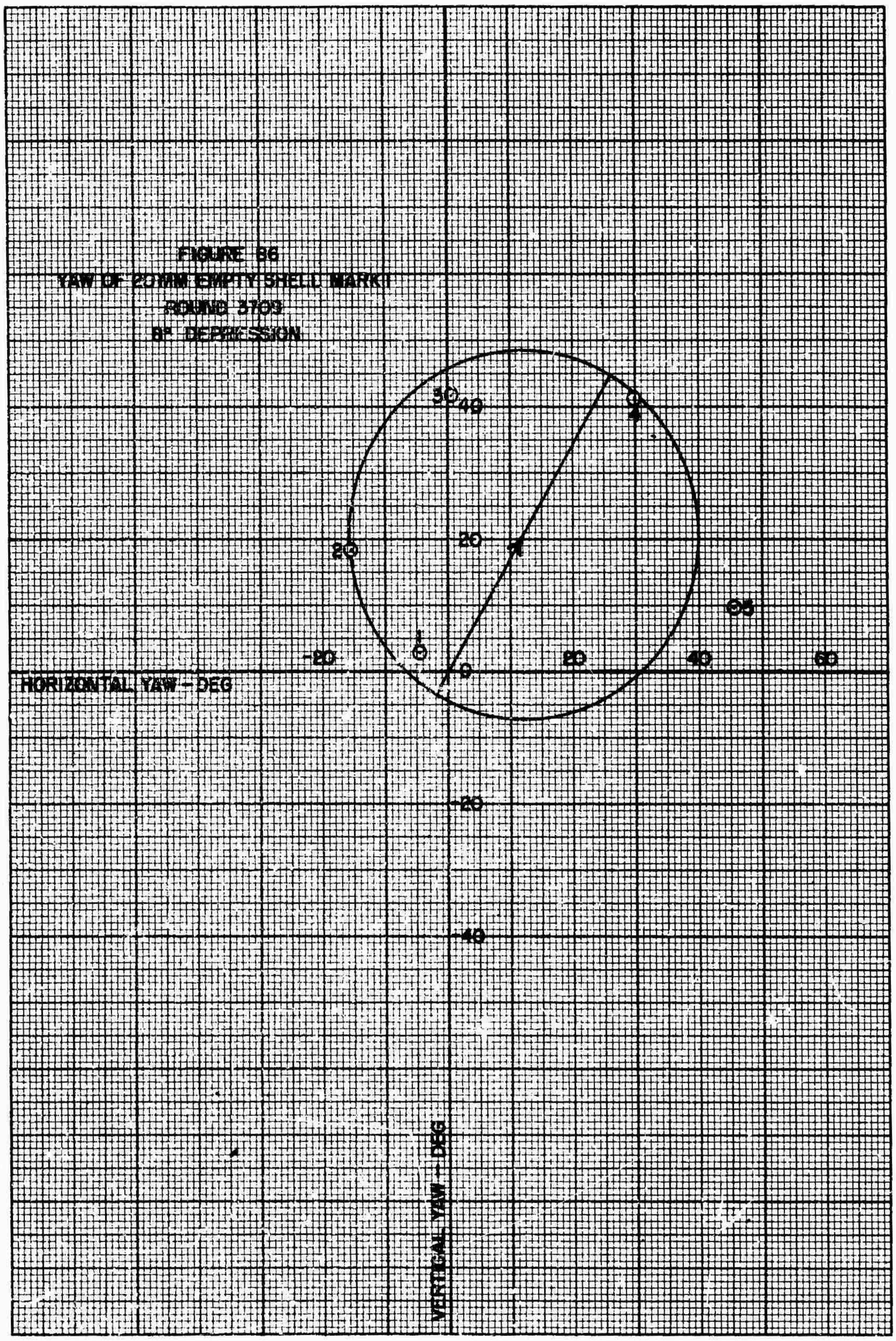


FIGURE 86
YAW OF 20MM EMPTY SHELL MARK I
ROUND 3709
8° DEPRESSION

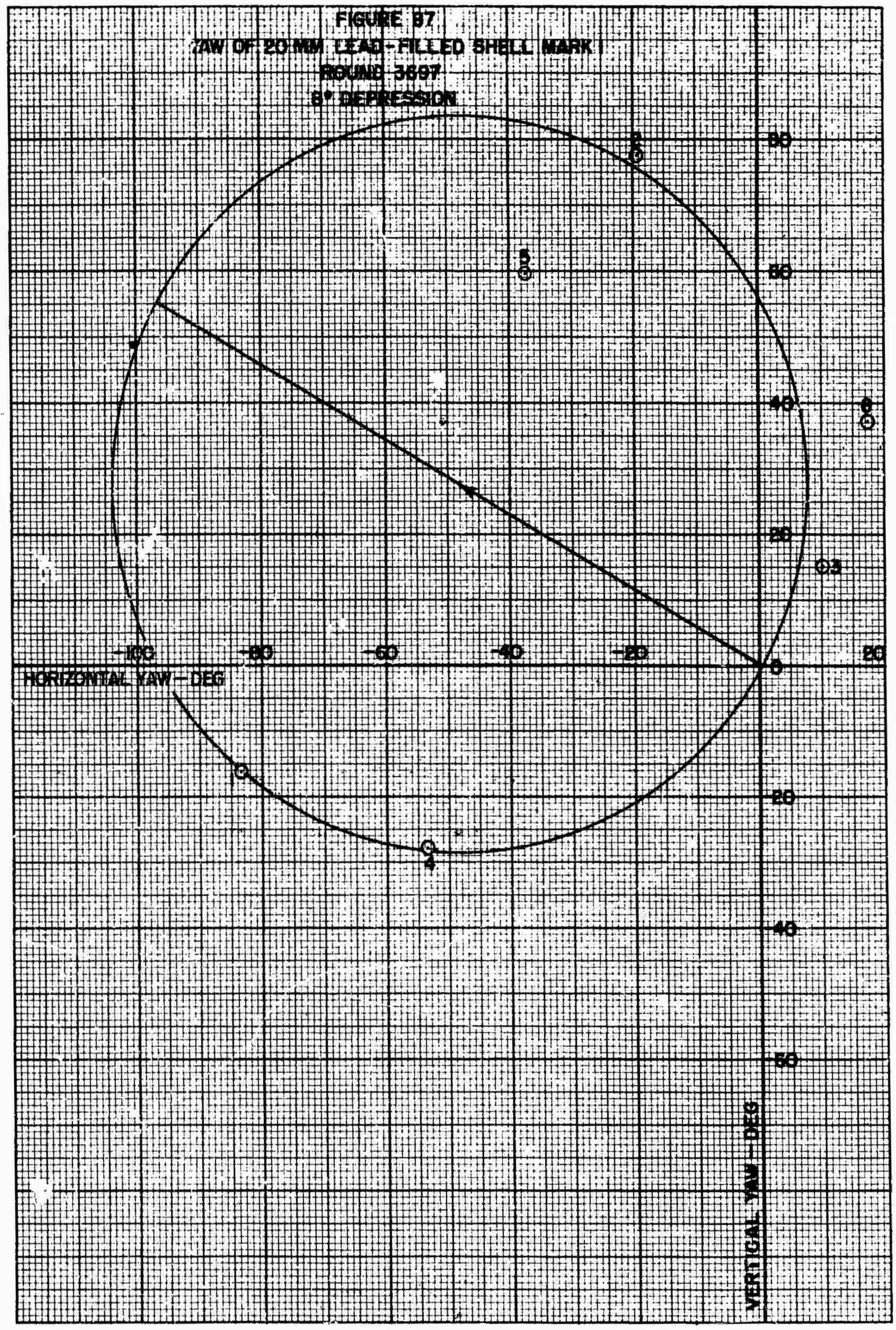


FIGURE 97
YAW OF 20 MM LEAD-FILLED SHELL MARK I
ROUND 3697
8° DEPRESSION
HORIZONTAL YAW – DEG
VERTICAL YAW – DEG
-100
-80
-60
-40
-20
0
20
80
60
40
20
20
40
60
2
5
6
3
4

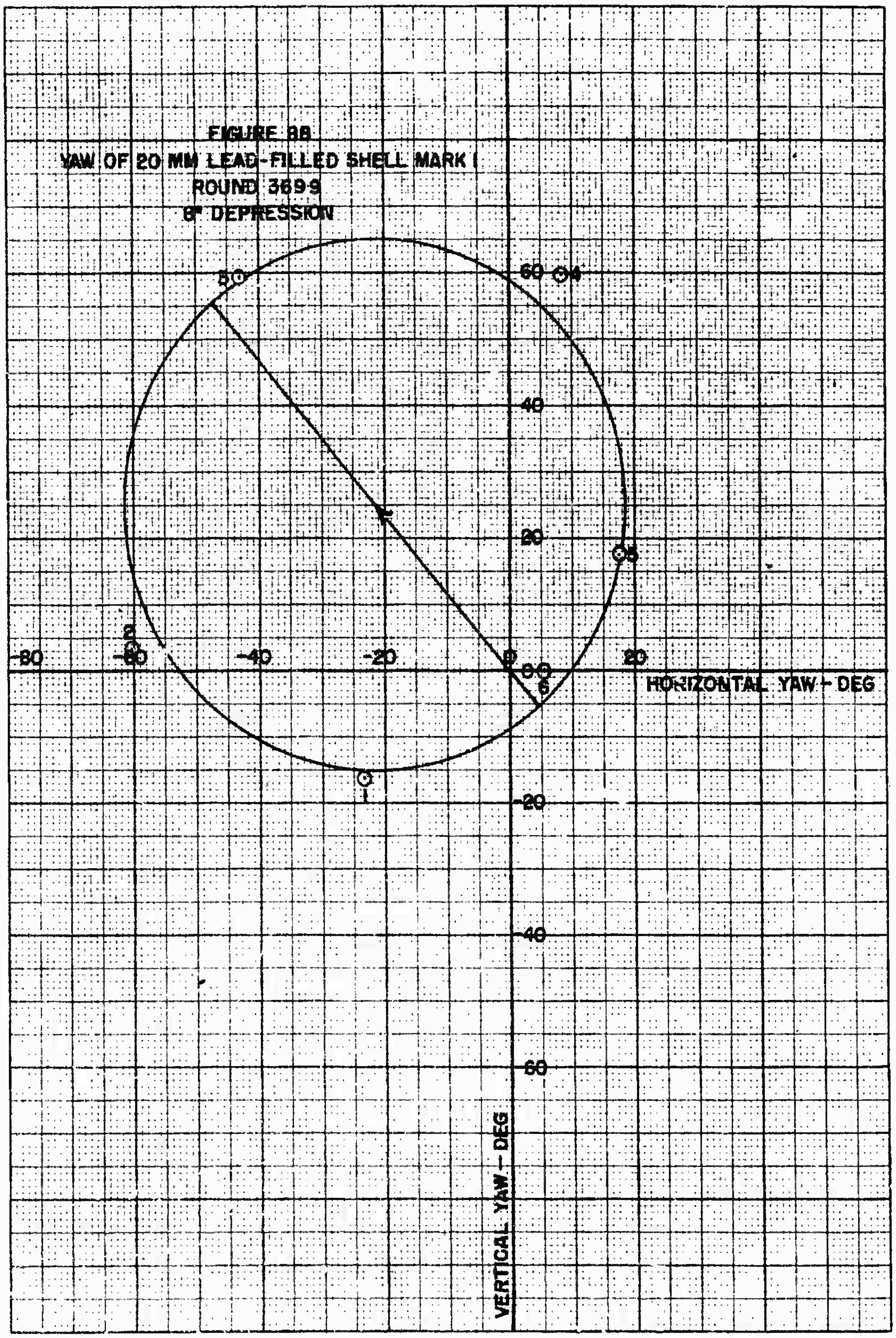


FIGURE 88
YAW OF 20 MM LEAD-FILLED SHELL MARK I
ROUND 3699
6° DEPRESSION

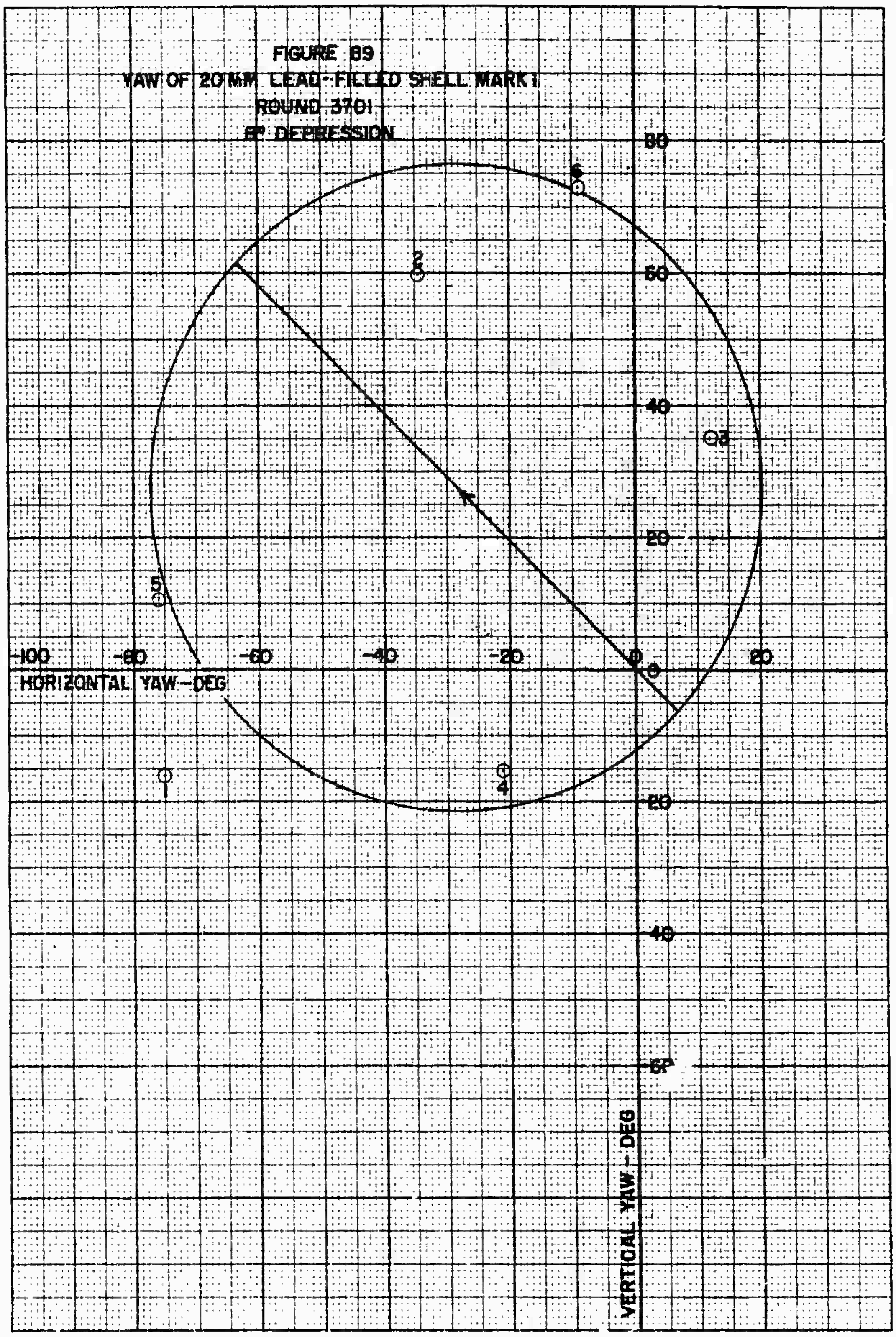


FIGURE 89
YAW OF 20 MM LEAD-FILLED SHELL MARK I
ROUND 3701
6° DEPRESSION
80
60
40
20
0
-20
-40
-60
-100
-80
-60
-40
-20
20
HORIZONTAL YAW—DEG
VERTICAL YAW—DEG
1
2
3
4
5
6

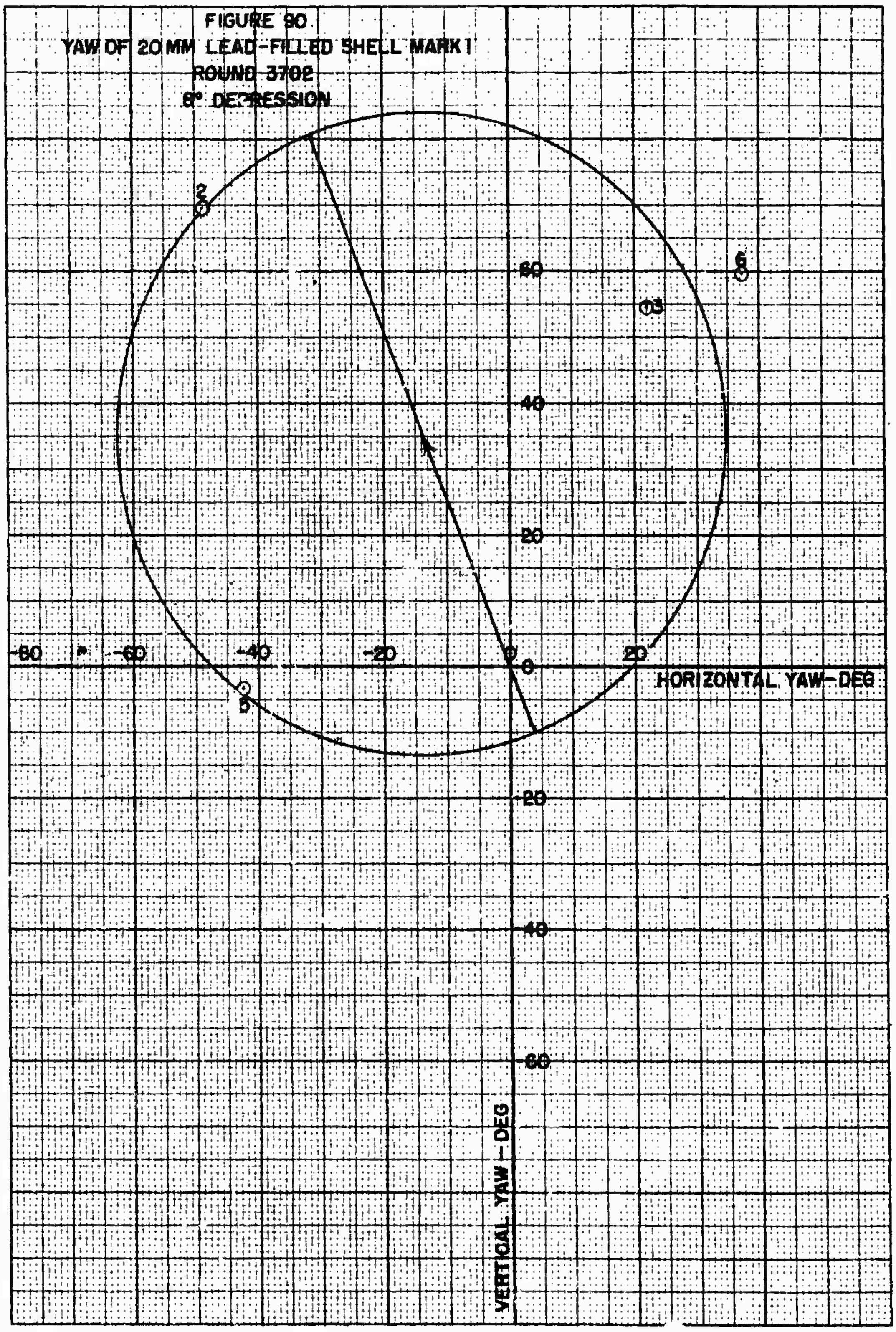


FIGURE 90
YAW OF 20 MM LEAD-FILLED SHELL MARK I
ROUND 3702
8° DEPRESSION

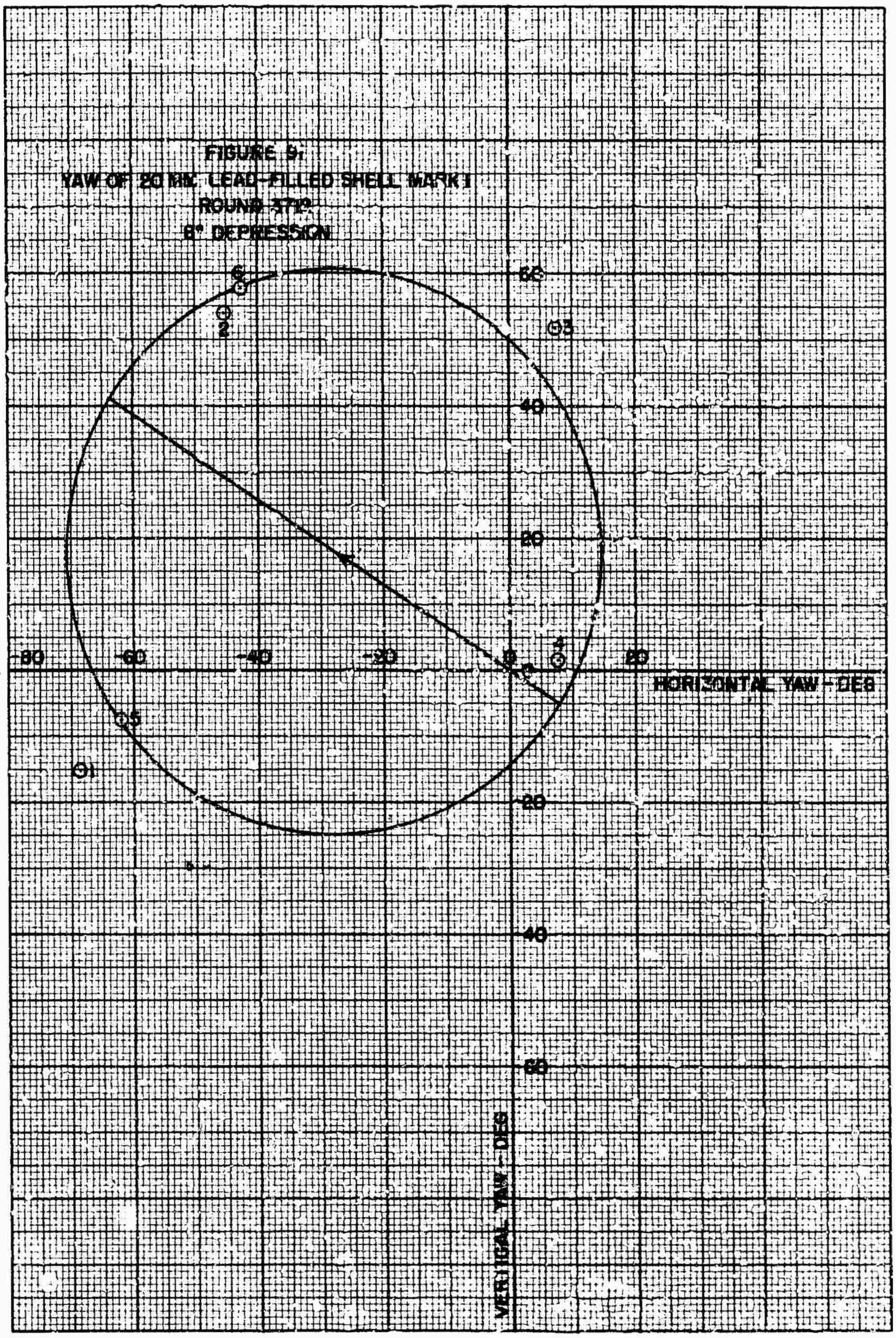


FIGURE 9.
YAW OF 20 MM. LEAD-FILLED SHELL MARK I
ROUND 3712
8° DEPRESSION

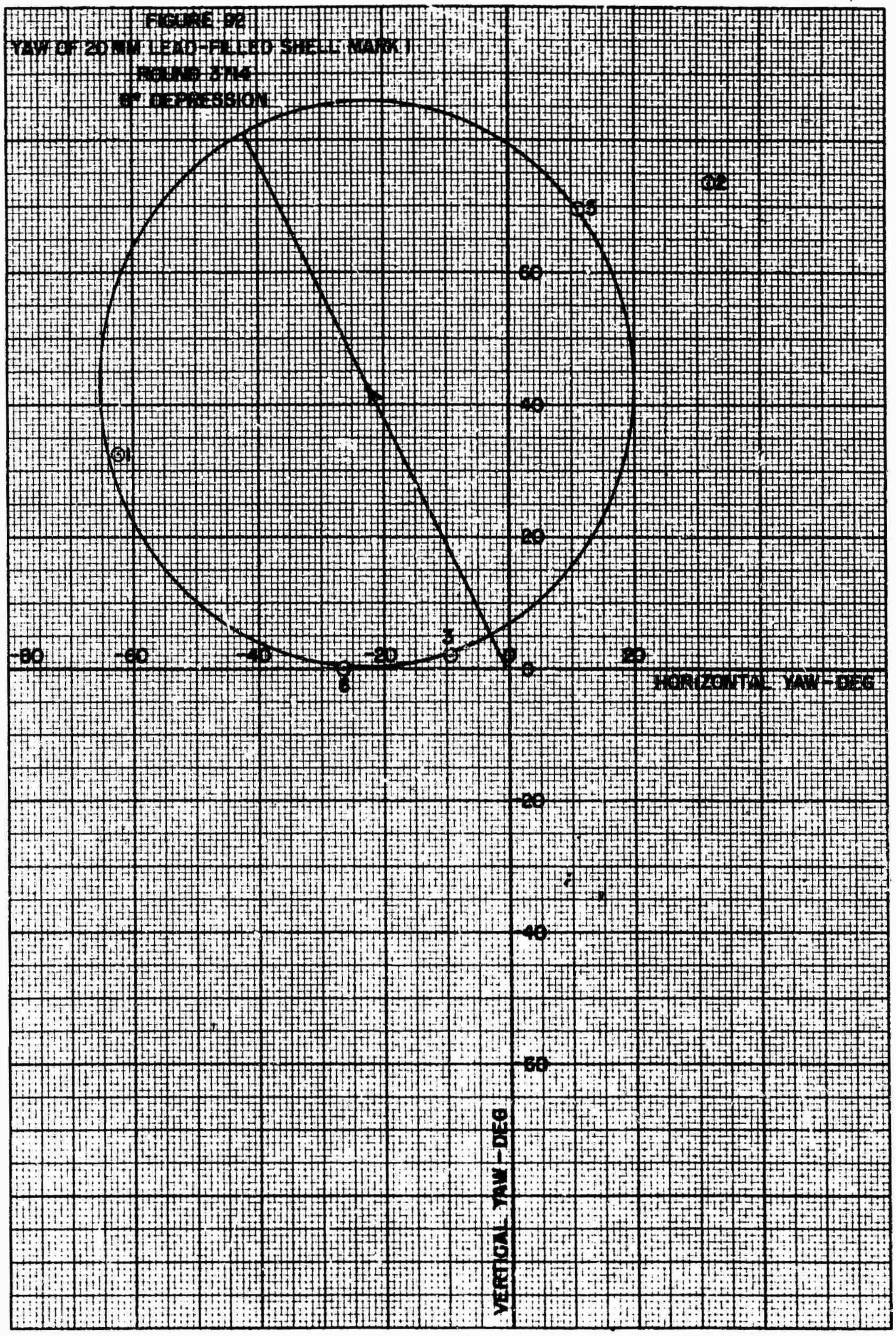


FIGURE 92
YAW OF 20 MM LEAD-FILLED SHELL MARK I
DEPRESSION
-80
-60
-40
-20
0
20
60
40
20
0
-20
-40
-60
HORIZONTAL YAW - DEG
VERTICAL YAW - DEG

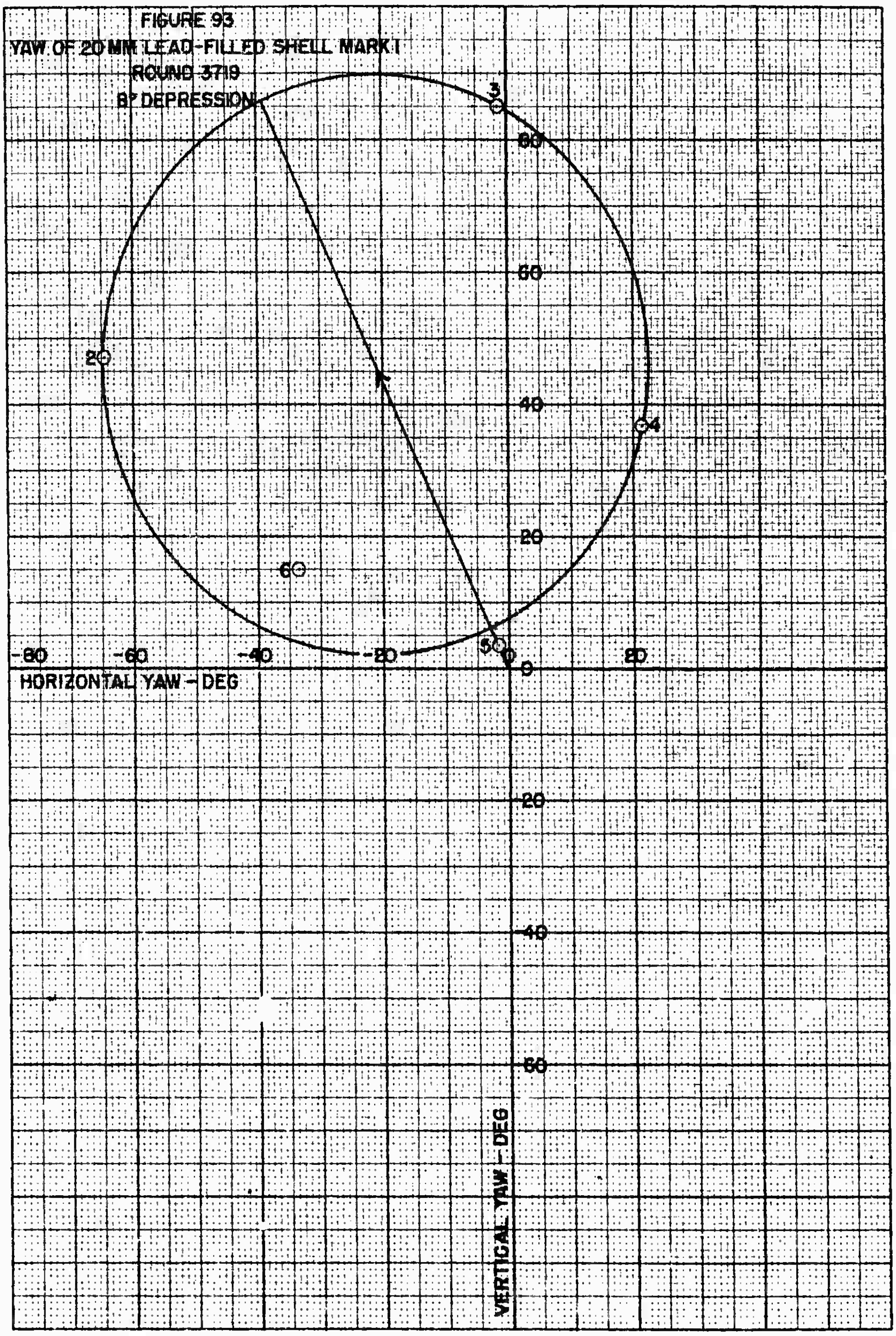


FIGURE 93
YAW OF 20 MM LEAD-FILLED SHELL MARK I
ROUND 3719
8° DEPRESSION
HORIZONTAL YAW - DEG
VERTICAL YAW - DEG
-80
-60
-40
-20
0
20
60
40
20
-20
-40
-60
1
2
3
4
5
6

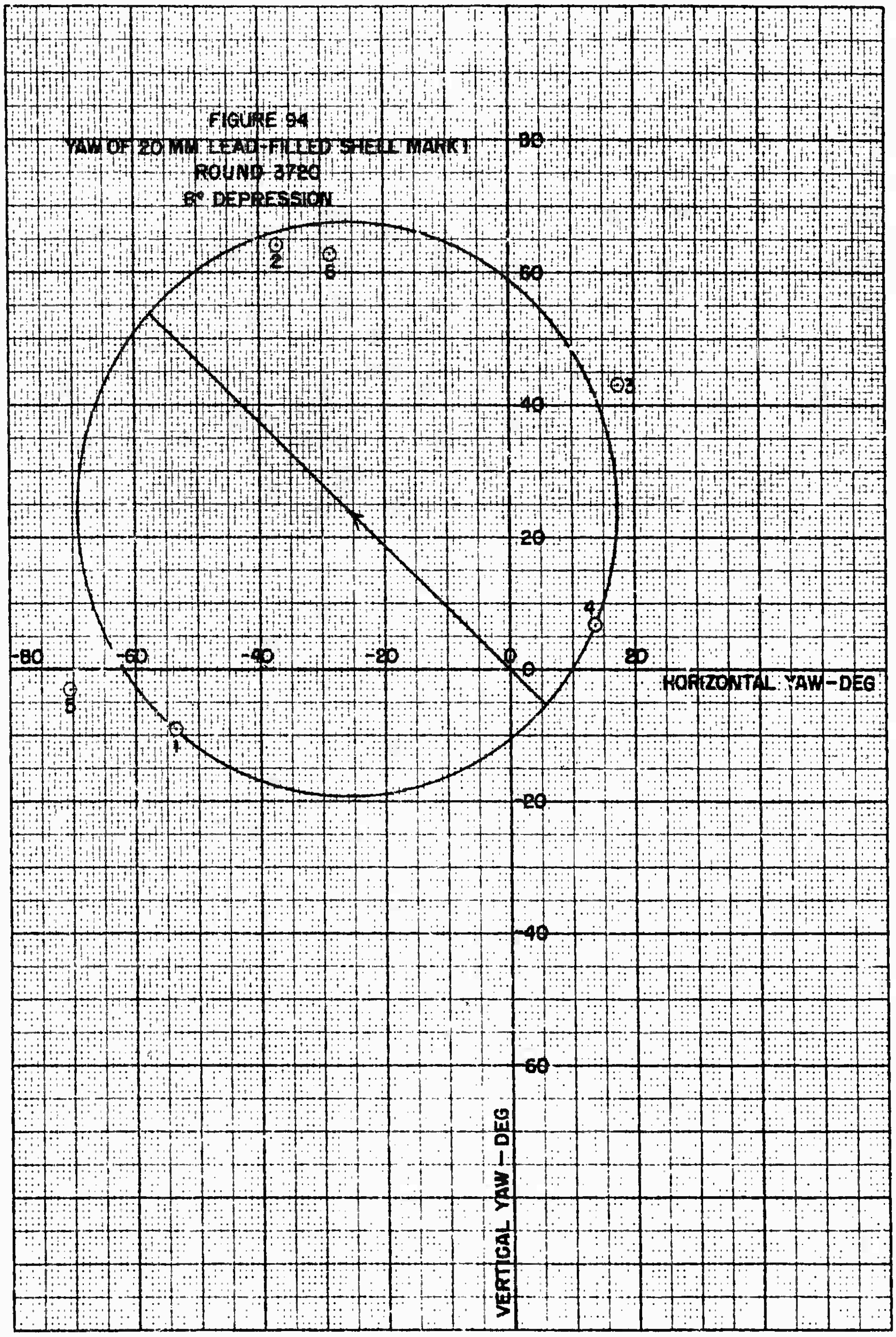


FIGURE 94
YAW OF 20 MM LEAD-FILLED SHELL MARK I
ROUND 3720
8° DEPRESSION
HORIZONTAL YAW—DEG
VERTICAL YAW—DEG
-80
-60
-40
-20
0
20
80
60
40
20
0
-20
-40
-60
1
2
3
4
5
6

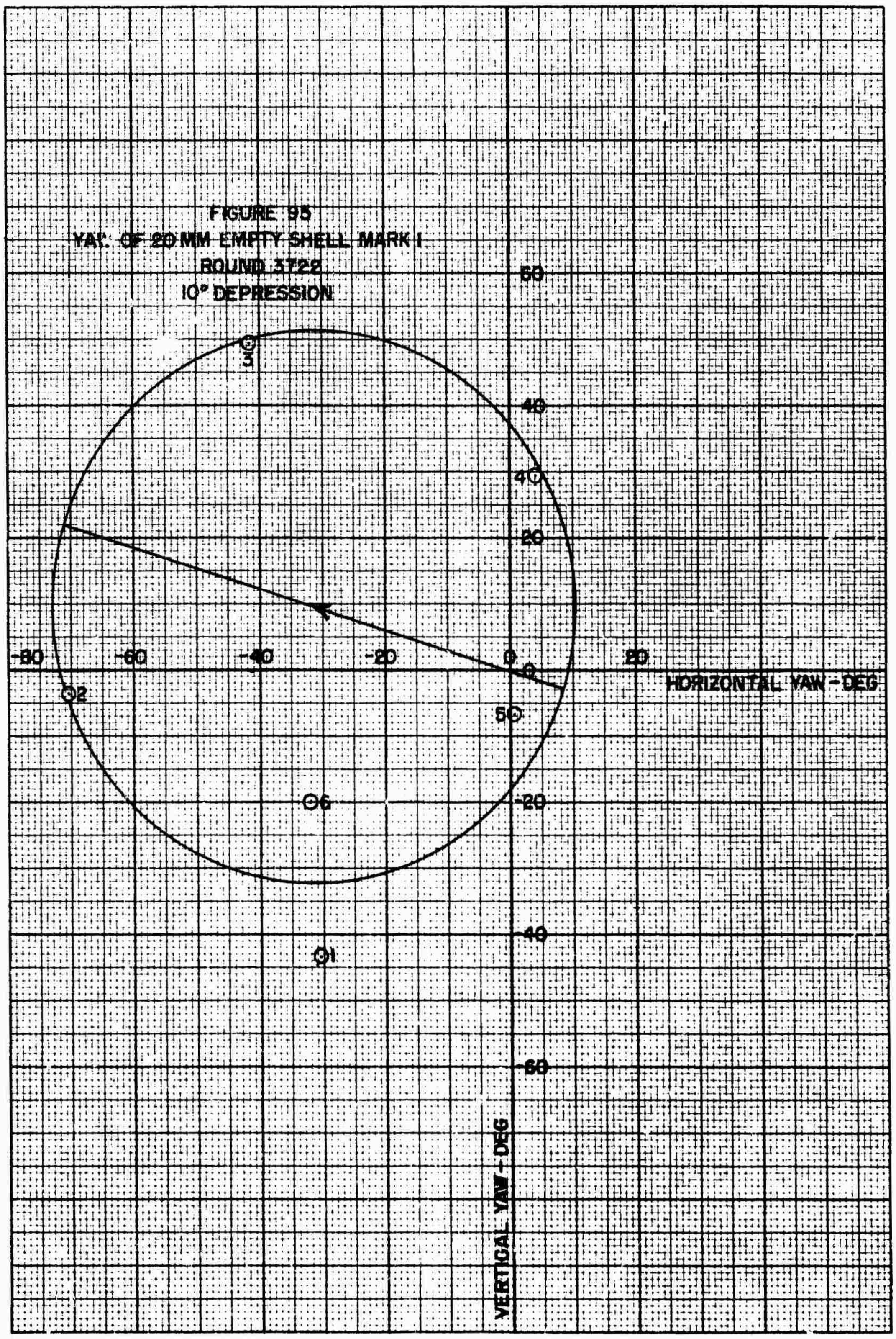


FIGURE 95
YAW OF 20 MM EMPTY SHELL MARK I
ROUND 3722
10° DEPRESSION
60
40
20
0
-20
-40
-60
-80
20
HORIZONTAL YAW - DEG
VERTICAL YAW - DEG
1
2
3
4
5
6

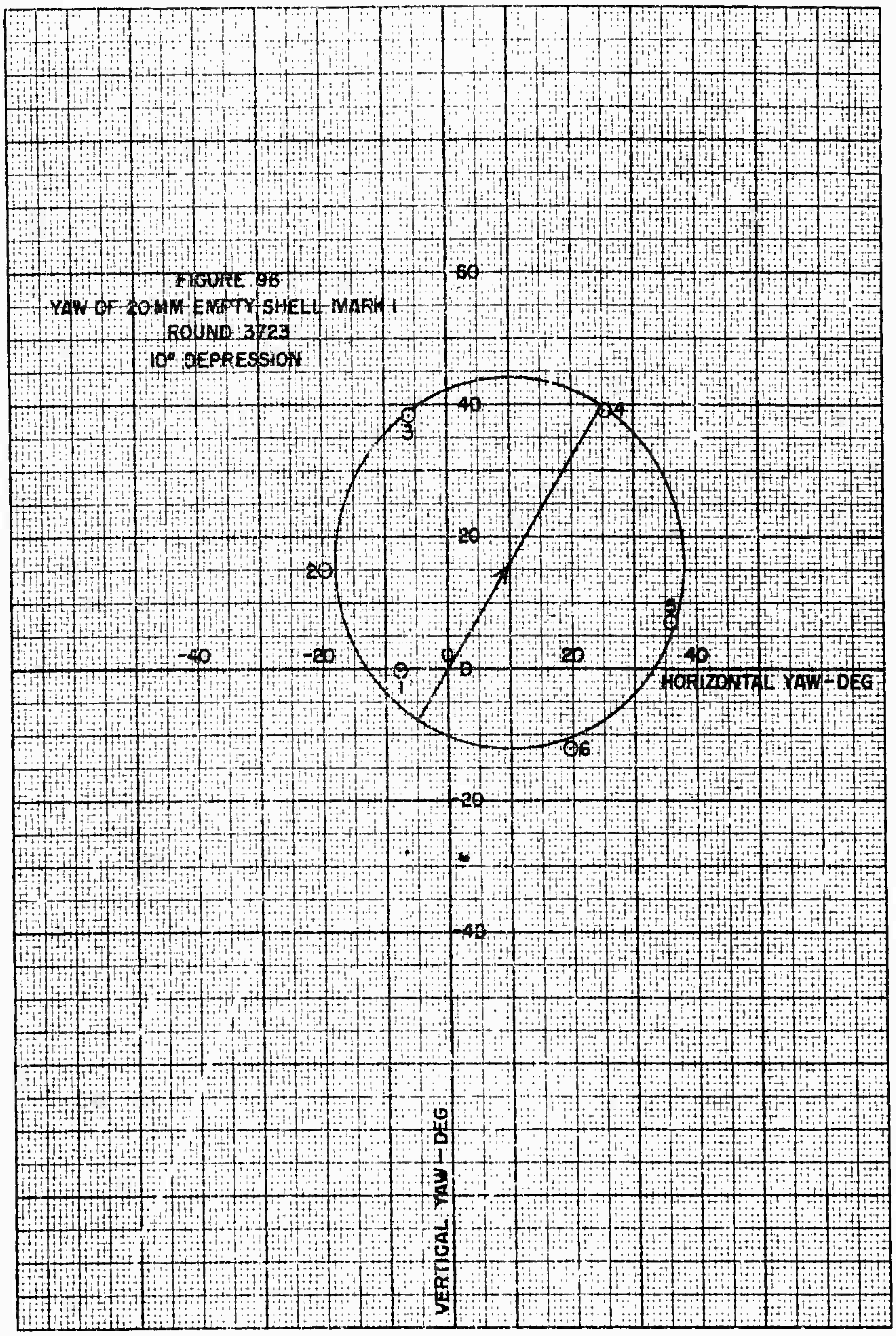


FIGURE 96
YAW OF 20 MM EMPTY SHELL MARK I
ROUND 3723
10° DEPRESSION
40
20
-20
-40
-40
-20
0
20
40
HORIZONTAL YAW - DEG
VERTICAL YAW - DEG
1
2
3
4
5
6

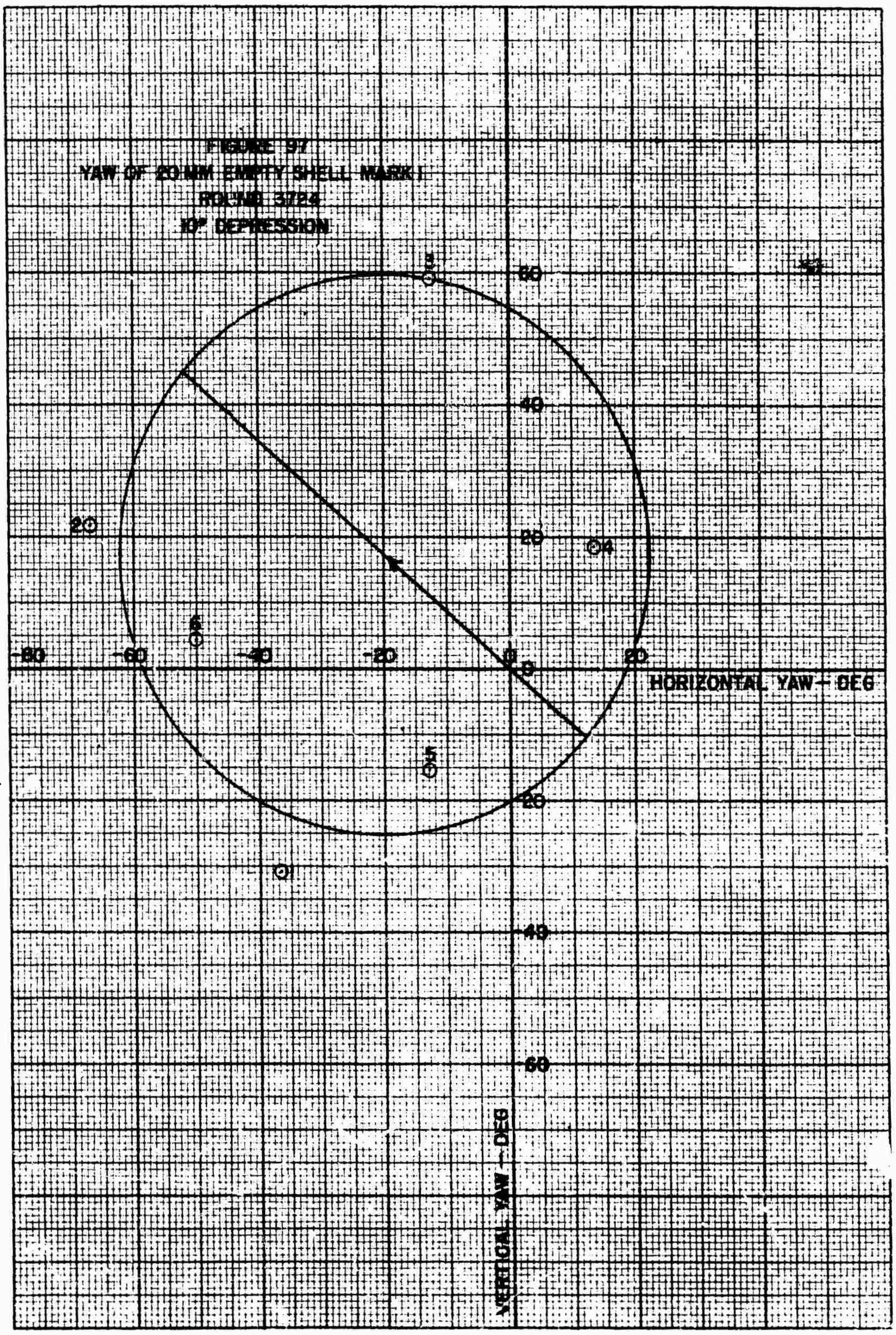


FIGURE 97
YAW OF 20 MM EMPTY SHELL MARK I
ROUND 3724
10° DEPRESSION

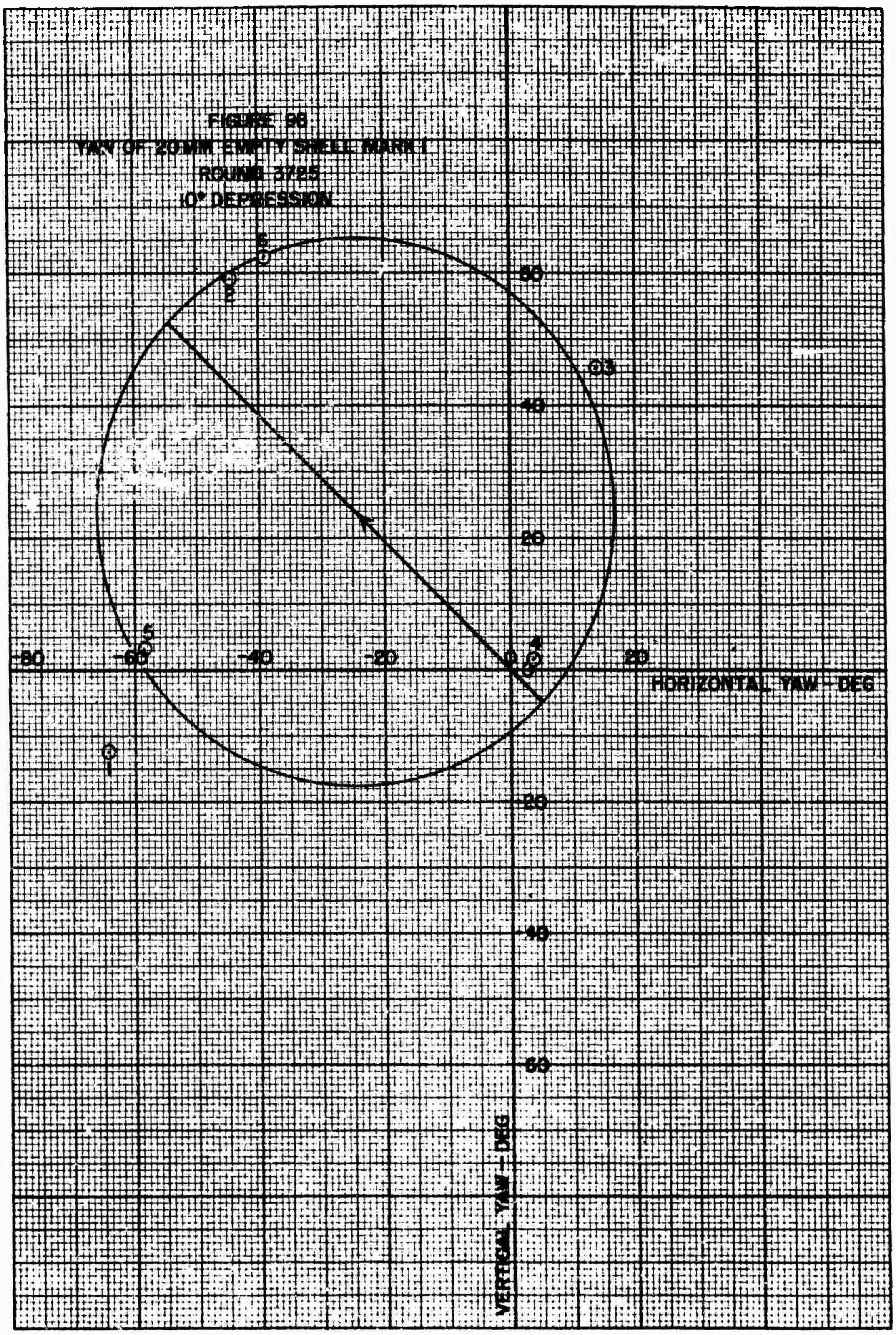


FIGURE 98
YAW OF 20MM EMPTY SHELL MARK I
ROUND 3725
10° DEPRESSION

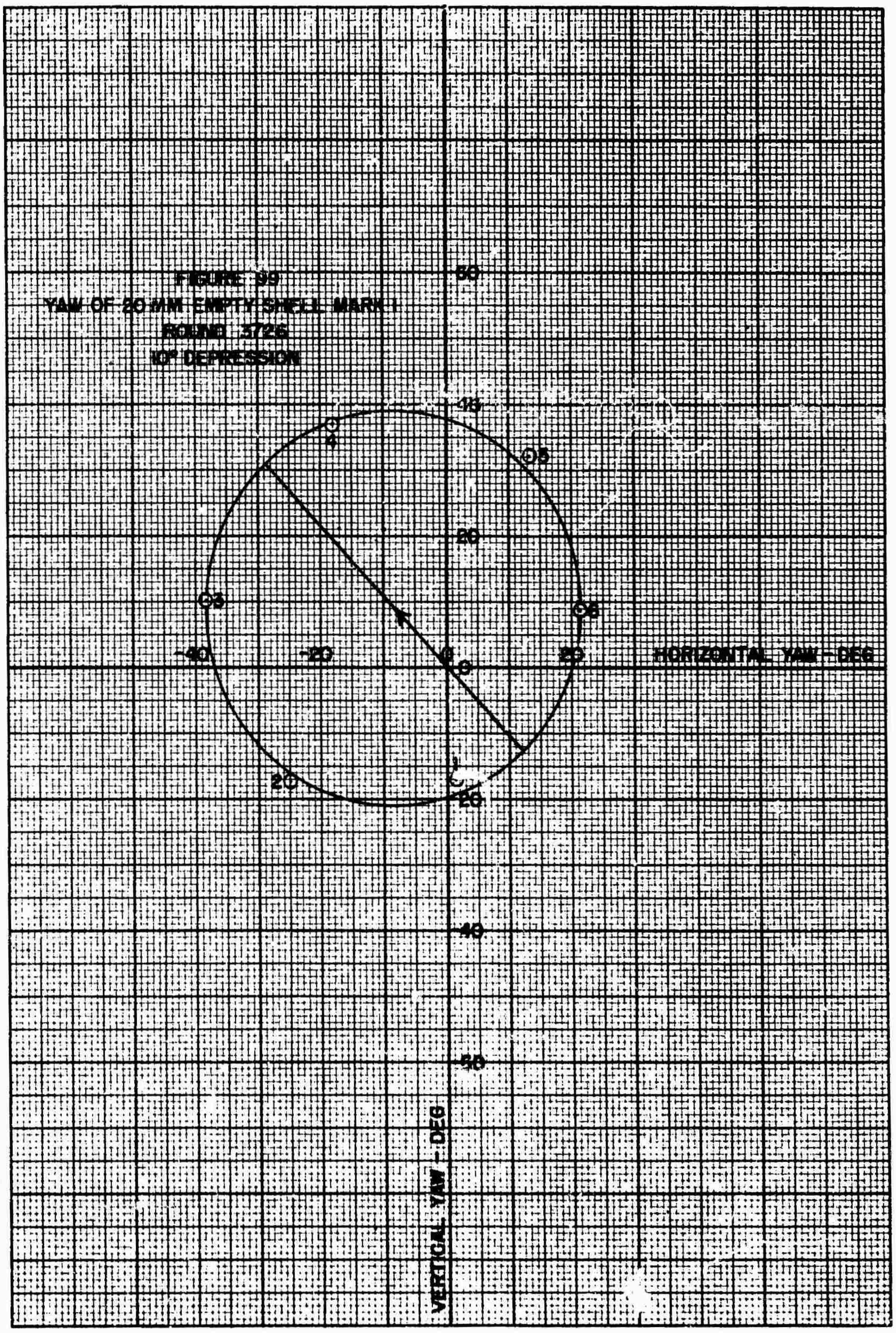


FIGURE 39
YAW OF 20 MM EMPTY SHELL MARK I
ROUND 3726
10° DEPRESSION

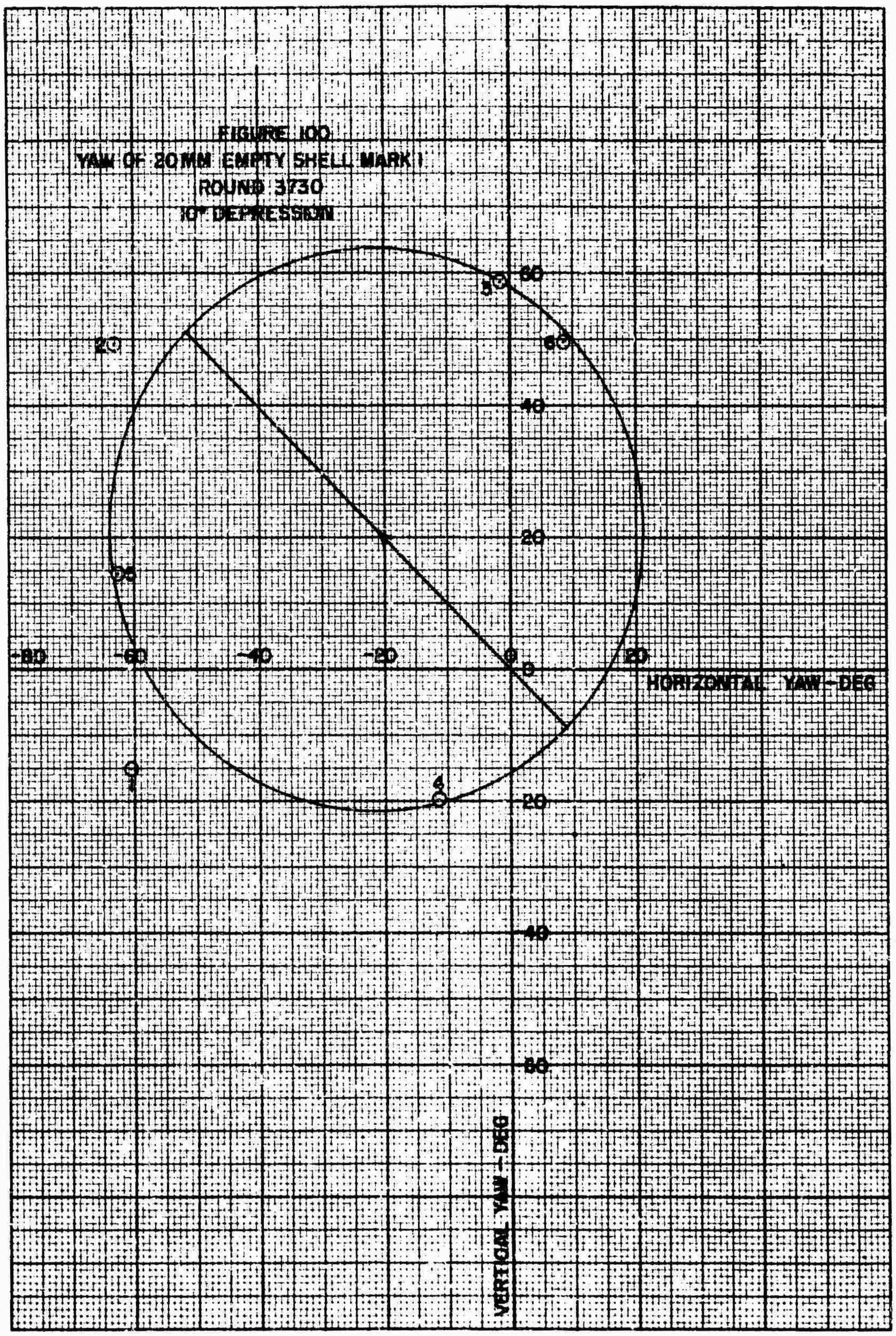


FIGURE 100
YAW OF 20 MM EMPTY SHELL MARK I
ROUND 3730
10° DEPRESSION
60
40
20
0
-20
-40
-60
-80
-60
-40
-20
0
20
HORIZONTAL YAW - DEG
VERTICAL YAW - DEG
1
2
3
4
5
6

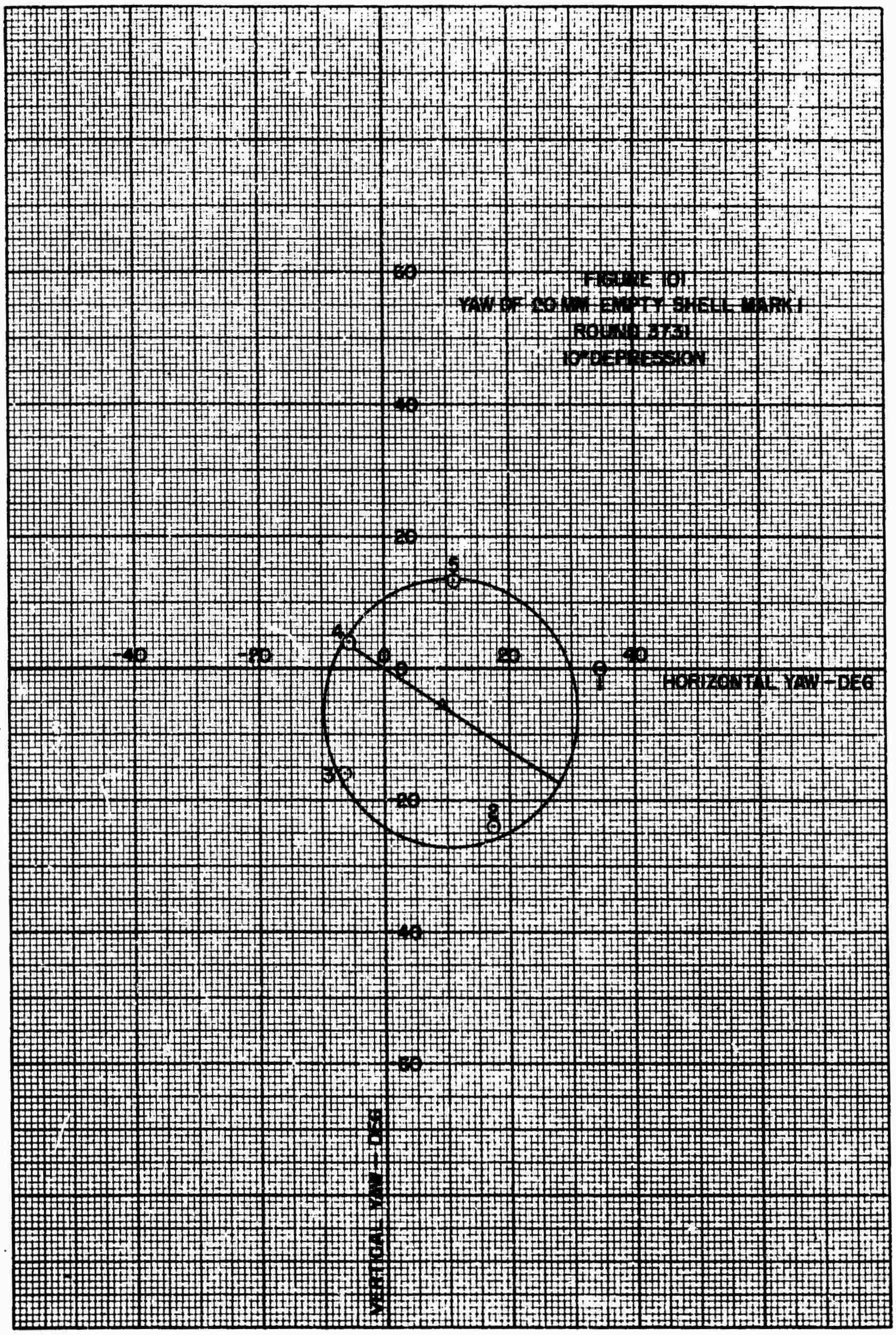


FIGURE 101
YAW OF 20 MM EMPTY SHELL MARK I
ROUND 3731
10° DEPRESSION

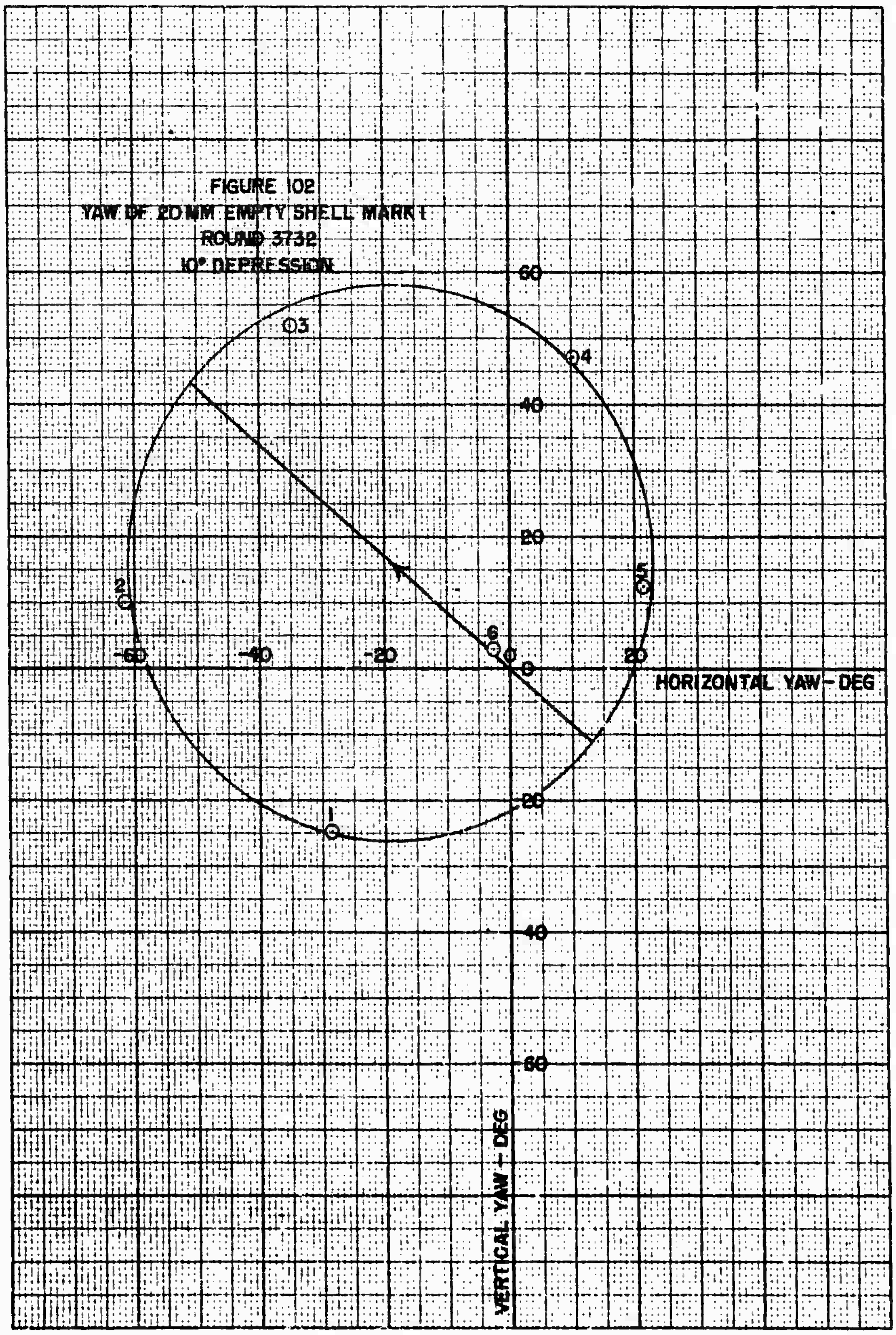


FIGURE 102
YAW OF 20 MM EMPTY SHELL MARK I
ROUND 3732
10° DEPRESSION
60
40
20
-20
-40
-60
-60
-40
-20
0
20
HORIZONTAL YAW - DEG
VERTICAL YAW - DEG
1
2
3
4
5
6

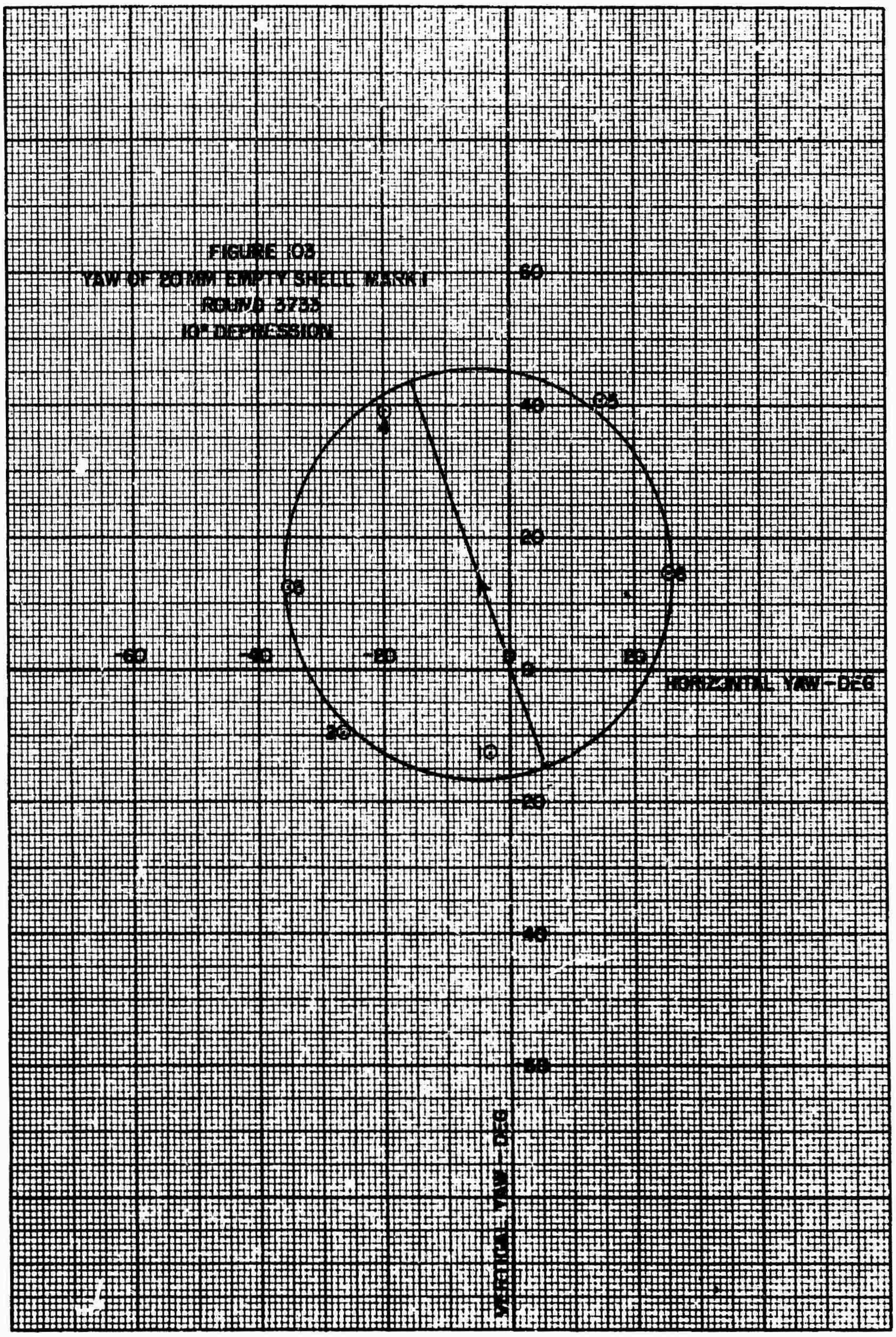
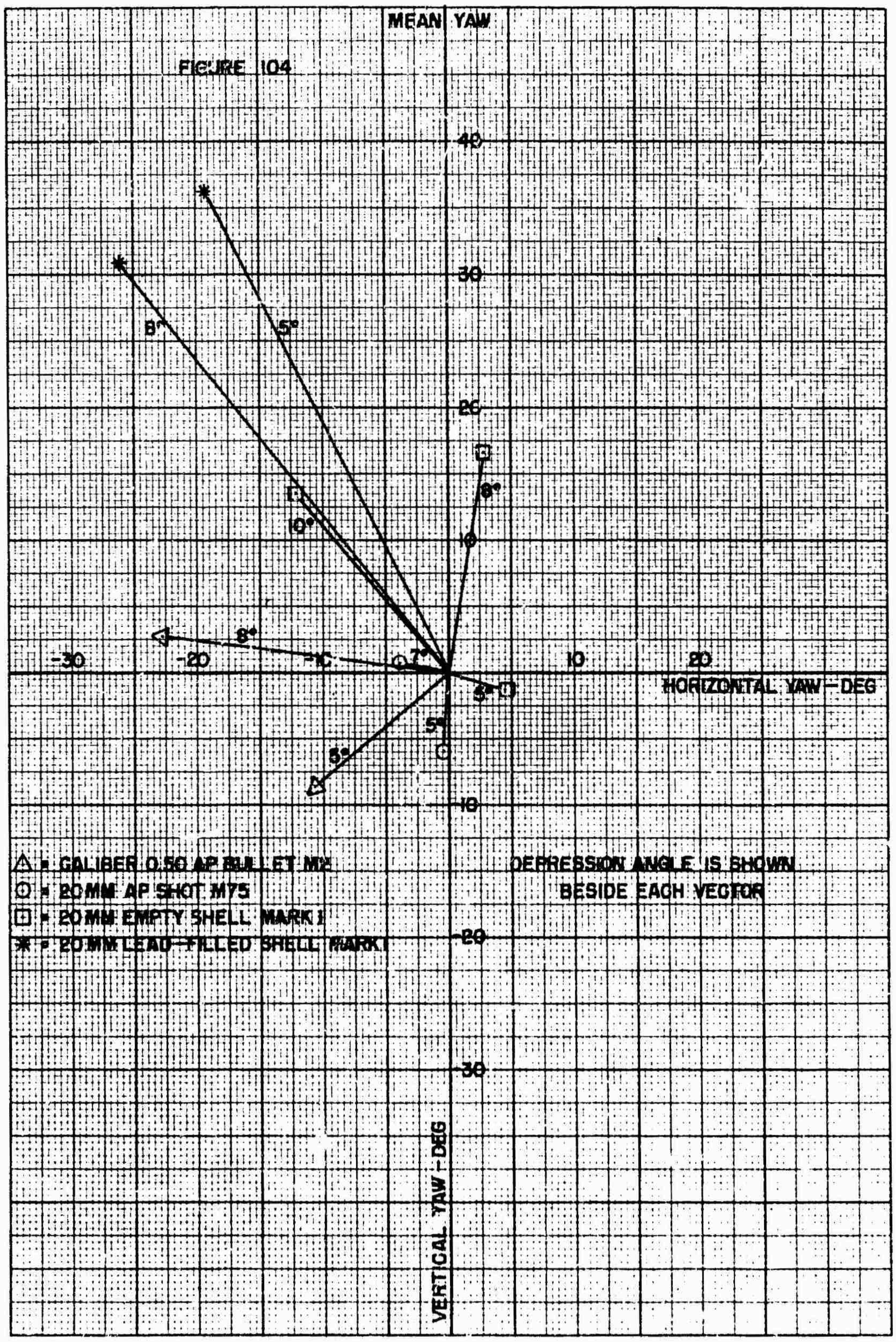


FIGURE 103
YAW OF 20MM EMPTY SHELL MARK I
ROUND 5733
10° DEPRESSION
HORIZONTAL YAW - DEG
VERTICAL YAW - DEG


MEAN YAW
FIGURE 104
HORIZONTAL YAW – DEG
VERTICAL YAW - DEG
△ = CALIBER 0.50 AP BULLET M2
○ = 20 MM AP SHOT M75
□ = 20 MM EMPTY SHELL MARK I
✱ = 20 MM LEAD-FILLED SHELL MARK I
DEPRESSION ANGLE IS SHOWN
BESIDE EACH VECTOR

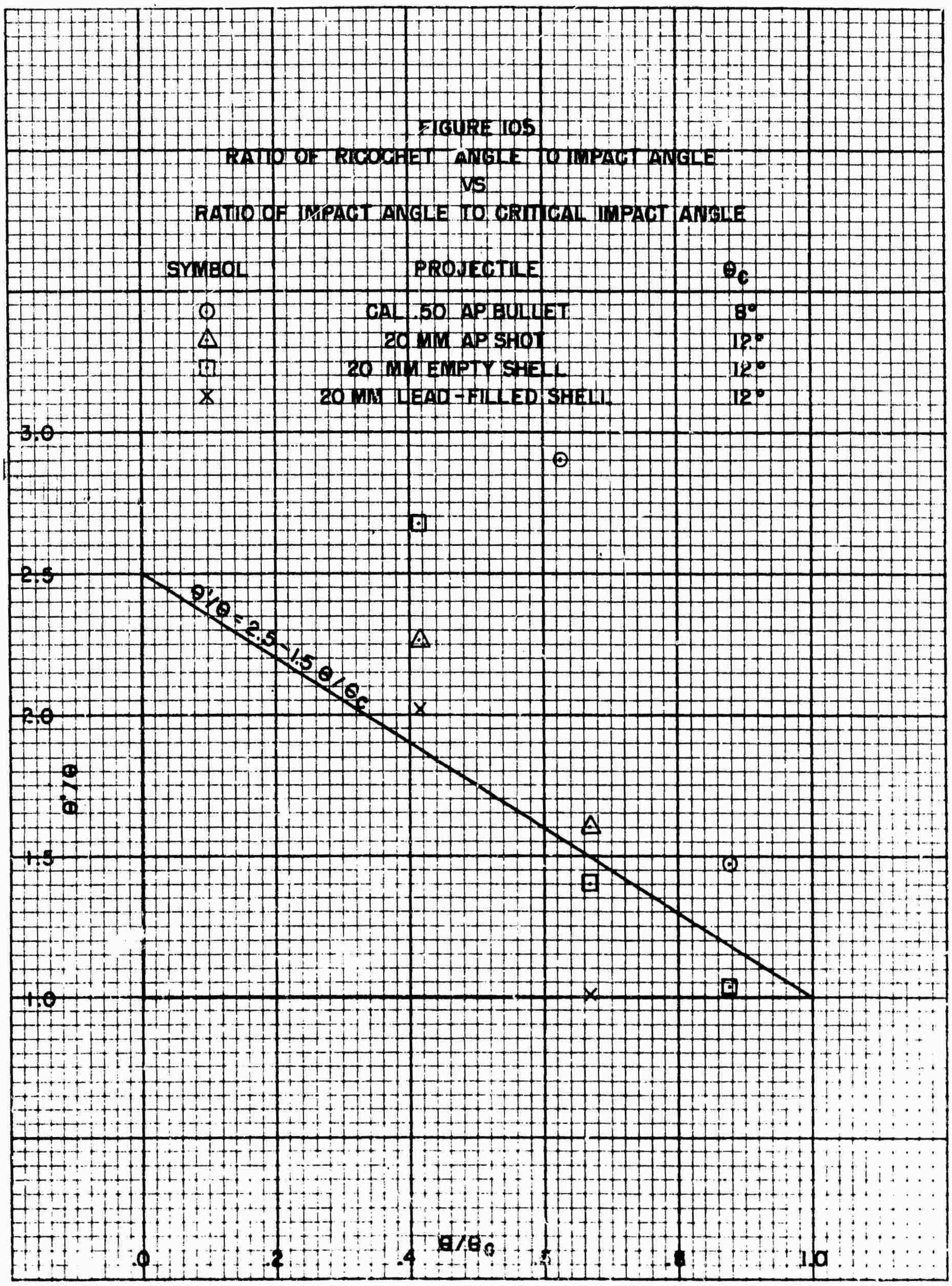


FIGURE 105
RATIO OF RICOCHET ANGLE TO IMPACT ANGLE
VS
RATIO OF IMPACT ANGLE TO CRITICAL IMPACT ANGLE
SYMBOL
PROJECTILE
θc
CAL .50 AP BULLET
8°
20 MM AP SHOT
12°
20 MM EMPTY SHELL
12°
20 MM LEAD-FILLED SHELL
12°
θ'/θ = 2.5 - 1.5 θ/θc
θ'/θ
θ/θc
3.0
2.5
2.0
1.5
1.0
0
.2
.4
.6
.8
1.0